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Report To:

Montana Water Pollution Council

January, 1965

Progress Report

on

Reduction of Wastes Reaching

the

Yellowstone River Drainage

in

Montana

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FOREWORD

Water Pollution of the Yellowstone River, particularly downstream from Billings, Montana, has been a problem which the State Board of Health has been endeavoring to correct for many years. Tastes and odors had been noted occasionally at various municipal water supplies using river water. There did not appear to be any similarity in the problem until 1950, when odors and tastes appeared in the drinking water during the months of November and December at about the time that catalytic cracking units were being installed at the oil refineries.

In the Laurel-Billings area, wastes from three oil refineries, a beet sugar refinery and two meat packing plants, together with treated sewage from the cities of Laurel and Billings are discharged to the river.

During the past few years, considerable improvement has been noted in the quality of water in the Yellowstone River as a result of improvement in sewage treatment facilities by the cities of Laurel and Billings. Two of the three oil refineries have modified their operations and provided extensive waste treatment facilities. The third refinery has installed many features in an effort to control the waste problem and has just completed an extensive study leading to complete control of the wastes. One of the meat packing plants is in the process of installing treatment facilities. The other is scheduled to commence construction of facilities in the near future. At the sugar beet refinery, the major portion of the wastes have been removed and some treatment of the wash and flume water was instituted in 1964. It is recognized that additional treatment must be given these wastes and this is now under study.

This report indicates progress on the continuing study of the Yellowstone River in the Billings area.

John S. Anderson, M.D.
Executive Officer

Report to Montana Water Pollution Council.- November, 1964

Progress Report on Reduction of Wastes Reaching the Yellowstone River

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SUMMARY

1. The taste and odor problems involving chlorophenol at communities downstream from Billings on the Yellowstone River is best explained as being a direct result of oil refinery wastes.

2. The Farmers Union Central Exchange Refinery and the Continental Oil Refinery have provided adequate waste treatment facilities. The Humble Oil Refinery has reduced its wastes considerably but needs additional treatment facilities. Humble Oil is presently constructing and planning additional facilities.

3. The sugar refineries have reduced the strength of their wastes considerably with the elimination of lime water and the pulp silo drainage. Settling facilities for the removal of suspended solids are still needed. The Great Western Sugar Co. at Billings has screening facilities planned for 1964.

4. The meat packing plants at Billings have not provided treatment for their wastes. Pierce Packing Co. will connect to the city treatment plant during 1964. It is expected that Midland Empire Packing Co. will construct treatment facilities during 1965.

5. All communities on the Yellowstone and Big Horn Rivers have sewage treatment or are in the process of constructing it. Four must add to or replace their present treatment facilities.

6. Biological studies indicate the improved condition of the Yellowstone River between Laurel and Billings due to installation of waste treatment facilities by the Farmers Union Oil Refinery at Laurel. Surveys to date demonstrate little improvement below Billings.

7. Monthly samples for phenols have been collected at Laurel, Billings, and Huntley since 1953. A comparison of the levels of phenolic compounds demonstrates the effect of water temperature on the survival of phenols in the river. Below 40° F, higher levels of phenols are present on the lower Yellowstone River.

8. A significant decrease of phenols has occurred in the Yellowstone River. Average phenols at Huntley below Billings still exceed the 5 ppb water quality objective of the Montana Water Pollution Council.

9. Since 1960, water samples for analysis of MPN (Most Probable Number) coliform organisms have been submitted by Laurel, Billings, Forsyth, Miles City and Glendive. The MPN at one city (used as an example) exhibits two peaks during the year - one in the spring and one in the fall. The higher numbers occur during the fall and appear to be the result of sugar beet refinery wastes as well as the colder water temperatures. The MPN'S have exceeded the limits established by the Montana Water Pollution Council in most instances. Further sampling and study is needed in this area.

RECOMMENDATIONS

1. That additional waste treatment facilities be provided by the Humble Oil Refinery at Billings,

2. That additional waste treatment facilities be provided by the sugar refineries.

3. That waste treatment facilities be provided by Midland Empire Packing Co. at Billings.

4. That new sewage treatment facilities be provided by Gardiner, Hysham, Highland Park Subdivision at West Glendive, and Fairview.

5. That additional dissolved oxygen data be obtained on the Yellowstone River.

6. That additional MPN coliform organism and other bacteriological data be obtained on the Yellowstone River.

7. That additional waste treatment and biological studies be made after industrial waste treatment facilities have been installed in the Billings area.

INTRODUCTION

Municipal water supplies taken from the lower Yellowstone River have developed severe taste and odor problems intermittently during the late fall and early winter. Difficulties have occurred at Hardin on the Big Horn River, and at Forsyth, Miles City, and Glendive, Montana on the Yellowstone. Less severe problems have been experienced at Billings. Williston, North Dakota, situated on the Missouri River downstream from the Yellowstone, has not reported any difficulties attributed to the Yellowstone since 1957.

The first complaint which was traceable to industrial wastes occurred during November and December, 1950, at which time the Montana State Board of Health solicited the aid of the U.S. Public Health Service. Tastes and odors at that time were traced to industrial operations located on the Big Horn River in Wyoming. The City of Billings reported serious taste and odor problems in November, 1952, and again in December, 1954. The 1952 episode was reported to be due to release of spent caustic high in phenols by the Farmers Union Refinery at Laurel. During 1954, tastes and odors which were reported at Forsyth, Miles City, and Glendive, did not coincide with tastes and odors at Billings. This condition persisted during most of the month of December, 1954. Again in December of 1957, 1960 and 1961 obnoxious tastes and odors were reported at Forsyth, Miles City and Glendive.

Surveys designed to inquire into the nature of stream conditons promoting unpalatable water quality were conducted cooperatively by the Montana State Board of Health and the U.S. Public Health Service in August and September, 1952. The study indicated several factors and combinations thereof that could periodically cause trouble. An acute taste and odor problem occurred in 1954 and extended to Williston, North Dakota. Complaints arising from this occurrence indicated the necessity of another survey to include quantitative measurement of various waste components discharged to affected streams, more extensive laboratory work, and carbon filter studies. Therefore, a cooperative study involving the State Health Departments of Montana and North Dakota, and the U.S. Public Health Service was initiated in 1955 (U.S.P.H.S., et al. 1956).

The 1955 study concluded that river pollution was excessive and an immediate and aggressive program of abatement was fully warranted. Recommendations were made at that time to industries for pollution abatement.

Results of a general stream survey of the Yellowstone River Basin in 1960 indicated that the Yellowstone River below Billings was still substantially affected by wastes entering at Billings (Hayes & Willems, 1964). Improvement was noted between Laurel and Billings due to completion of waste treatment facilities by the Farmers Union Central Exchange Refinery.

A survey of the Yellowstone River and industrial waste discharges in the Billings area was initiated in 1961 with the following objectives: (a) to determine the effect of municipal and industrial wastes upon the various water uses of the Yellowstone River; (b) to attempt to pin-point the source of taste and odor problems in water supplies downstream from Billings; (c) and to monitor changes as waste treatment facilities are added. This report is a progress report of the continuing study. Also included are routine data collected over a period of several years.

Effects of Taste and Odor Producing Compounds

The introduction of taste and odor producing substances into the Yellowstone River system by natural or artificial means adversely affects: (1) the use of the water as a source of domestic supply for individuals and communities; and (2) the food and sport fishery.

In general, the obnoxious taste and odor of drinking water reported during the fall and winter has been described as "chlorophenolic". The Yellowstone River between Billings and Custer is reported to be used little for fishing due to the "oily" taste of fish.

Probable Source and Cause of Tastes and Odors

Sugar beet refinery wastes have been alleged to be the cause of taste and odor problems. The Great Western Refinery at Billings has been in operation since 1907. The Holly Sugar Company Refinery at Hardin began operations in 1935. However, acute taste and odor problems did not develop until about 1950.

During all serious taste and odor problems on the Yellowstone River since 1952, with the exception of 1957, high phenol concentrations have been found at the municipal water intakes downstream from Billings. In 1957, the peak of a wave of phenols may have passed before water sampling was initiated. During 1960, a carbon filter was operated at Forsyth during the taste and odor period. The U.S. Public Health Service analyzed the carbon from the filter and made the following comment:

> "Without having observed the condition of the water itself, it is difficult for us to say what the exact cause of taste and odor was. However, the analysis evidence is very strong for phenols and other hydrocarbon pollutants usually associated with petroleum wastes."

Catalytic cracking of oil, first initiated by the refineries in the Yellowstone drainage during the late 1940's, produces large amounts of phenols. River sampling indicates that assimilation of the oil refinery waste products by the aquatic community of flora and fauna acts to render the waste innocuous during the summer season. Further, high-water dilution during the spring probably alleviates the problem during this season of the year. With the advent of cold weather in combination with the low stream flows prevalent during the early winter, microbiological assimilation of the waste is retarded and when greater than normal discharges of refinery wastes are produced, conditions leading to taste and odor in the drinking water of downstream communities are produced. This is the simplest explanation and immediately poses the question, "If the problem is primarily one produced by cold weather, why does it not continue until the high-water period?"

The most probable answer takes into consideration the seasonal discharge of sugar beet refinery wastes to the river. The occurrence of the obnoxious tastes and odors in the past has been coincidental with the sugar beet processing campaign during the fall of the year. It has been suggested by microbiologists of the U.S.P.H.S., Robert A. Taft, Sanitary Engineering Center, that these wastes are a contributory influence to the development of tastes and odors by providing a preferential food supply for the bacteria.

Results of sampling at the Great Western Sugar Refinery at Billings indicate very low concentrations of phenols in the sugar beet - concentrations that could not be measured after dilution in the Yellowstone River even if all the raw beet sugar juice produced was diverted to the river.

Phenols

Pure phenol, more commonly known as carbolic acid, and related compounds are produced by the destructive distillation of many organic materials, such as wood, coal, oil, etc. Natural degradation of tree leaves is also known to produce phenolic materials.

Standard Methods for the Examination of Water and Wastewater, 11th Edition (APHA et al., 1960) describes phenolic compounds, collectively referred to as "phenols", and as measured by the Gibbs method (formerly used by the Board of Health) and the aminoantipyrine method (presently used) "as those hydroxy derivatives of benzene, or its condensed nuclei," which can be measured by these methods. It is further stated that these methods determine such phenols as phenol, the ortho- and meta- substituted phenols in which the substituent is a carboxyl, halogen, methoxyl, hydroxy, or sulfonic acid group. These methods are insensitive to paracresol and similar para- substituted derivatives. It should be recognized that the total amount of phenol-like material in a typical refinery waste sample is not being measured by the method used.

Standard Methods mentions that the presence of as little as one ppb (part per billion) of the chlorinated phenols can impart a taste to drinking water. The limits for any particular effect are dependent upon factors such as the quality and the temperature of the water, the composition of the phenols present, and the amount of chlorine used. Break-point chlorination, where larger amounts of chlorine are used, is reported to lessen the taste and odor problem in instances.

The Montana Water Pollution Council has established five parts per billion as the maximum concentration of phenolic material in a Class A or B water supply. The Yellowstone River and tributaries above Gardiner have been classified as a Class A water supply, and below Gardiner as a Class B water supply.

Oil Refineries

Gasoline manufacture is for the most part, a chemical manipulation of the complex hydrocarbon structure of petroleum. The first step in the refining process is distillation. Heat physically separates the various portions of the hydro-carbons according to their boiling ranges with the lighter,low-boiling range fractions vaporizing first in the stills after heating leaving the heavier, higher-boiling range fractions.

Some of the fractions from distillation fall within the gasoline boiling range and may be used,per se,blending gasoline. Other fractions may be used for products such as liquified petroleum gas, heating oil or asphalt. As the demand is greater for gasoline, the fractions that are too light or too heavy for gasoline may be put through additional refinery processing that converts them into fractions suitable for gasoline blending.

One of the major processes for this operation is catalytic cracking, in which oil fractions pass over a catalyst. The catalyst, in conjunction with heat and pressure, breaks down or "cracks" the molecular structure of heavier oil fractions into lighter components that can be used in gasoline blends. Another process, catalytic reforming, is used to improve the octane quality of heavy gasoline fractions produced by distillation. Other catalytic processes (polymerization and alkylation) convert light gases from distillation and cracking into heavier fractions that are suitable in gasoline.

Wastes in oil refineries arise mainly from the separation of condensed steam that has been in direct contact with a hydrocarbon in one of the refining processes; spent caustic which removes sulphides and phenols from the product; and miscellaneous oil losses from throughout the plant.

Of major concern to the State Board of Health at the present time are the phenols, cresols and similar materials which can create tastes and odors in downstream water supplies. The potential for oil refineries to discharge large quantities of phenolic material during a short period of time is of particular concern.

Figure 1. Phenolic compounds in oil refinery effluents discharged to the Yellowstone River, 1955-63.

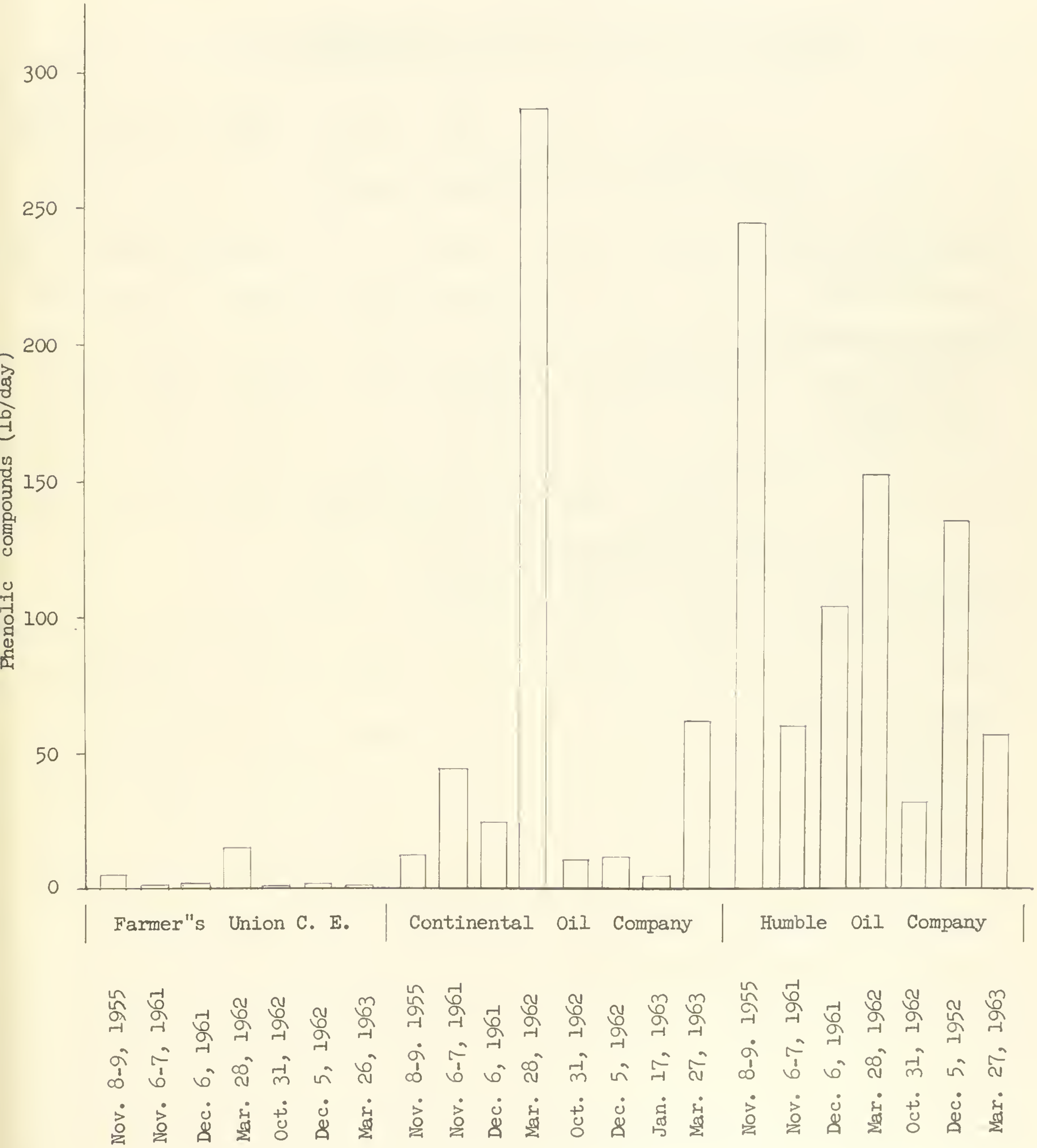


TABLE I

Volume of crude oil refined, waste flow, and phenolic compounds discharged to the Yellowstone River by oil refineries and volume of river flow, 1955-63.

	Nov 8-9 1955	Nov 6-7 1961	Dec 6 1961	Mar 28 1962	Oct 31 1962	Dec 5 1962	Mar 27 1963
Farmers Union Central Exchange - Laurel							
Vol. of crude oil refined (bbl/day)	13,477	14,000	14,000	-	19,000	19,200	17,000
Waste flow (cfs)	1.16	0.45	0.45	0.41	0.56	0.45	0.28
Phenolic compounds (lb/day)	5.8	0.4	0.5	16.0	0.1	0.2	0.1
(lb/day/1,000 bbl crude)	0.4	0.03	0.03	-	0.00	0.01	0.01
(computed ppb in river)	0.4	0.02	0.03	0.73	0.01	0.01	0.01
River flow	3,000	4,000*	4,000*	4,000*	3,000*	3,000*	2300*
Continental Oil Company							
Vol. of crude oil refined (bbl/day)	10,418	12,000	14,400	-	15,200	15,400	17,500
Waste flow (cfs)	0.22	0.40	0.28	0.45	0.57	0.22	0.52
Phenolic compounds (lb/day)	13.7	44.5	18.0	287	10.5	10.9	67
(lb/day/1000 bbl crude)	1.3	3.7	1.3	-	0.7	0.7	3.8
(Computed ppb in river)	0.7	1.7	0.9	12.0	0.6	0.6	4.7
River flow	3,550	4,710	3,550	4,450	3,300	3,360	2,630

(Table I continued next page)

* Estimated from USGS Measurements

Table I Continued

	Nov 8-9 1955	Nov 6-7 1961	Dec 6 1961	Mar 28 1962	Oct 31 1962	Dec 5 1962	Mar 27 1963
Humble Oil Company							
Vol. of crude oil refined (bbl/day)	18,100	-	33,500	-	35,000	30,000	36,300
Waste flow (cfs)	39	40	43	55	58	42	64
Phenolic Compounds							
(lb/day)	244	60	103	152	32	137	56
(lb/day/1000 bbl crude)	13.5	-	3.1	-	0.9	4.5	1.5
(computed ppb in river)***	12.6	2.4	5.4	6.3	1.7	7.5	4.0

*** River flow same as for Continental

Phenolic materials as measured in the Yellowstone River during the 1961 and 1962 stream surveys are shown in Table 2. The computed concentration in the river after discharge by the oil refineries is also shown.

TABLE 2

Concentrations of phenolic compounds in the Yellowstone River, Nov., 1961 to Dec., 1962.

Station	Mileage from Laurel	Phenolic compounds (ppb)				
		Nov 6-7 1961	Dec 6 1961	Mar 28 1962	Oct 31 1962	Dec 5 1962
Laurel Water Intake	0	8	0	0	0	4
Billings Water Intake	20.8	7	2	2	0	4
O'Leary's Gravel Pit	22.1	6	0	12		18
Above Humble Oil Refinery	23.3	76	70	14		4
Below Humble Oil Refinery	24.5	13	34	30		26
Huntley	33.4	3	6	12		4
Computed Oil Refineries discharge to river (ppb in river)		4	6	19	8	2
River flow (cfs)		4,710	3,550	4,450	3,300	3,360

The average of computed quantity (7.8 ppb) is about 25 per cent higher than the average value actually determined by analysis (6.2 ppb) at Huntley. This can be expected since some degradation probably occurs in the section of the river between Billings and Huntley. Figures 2 and 3 indicate the location of sampling stations. It should be noted that there is incomplete mixing of wastes with the river at the O'Leary's Gravel Pit, above Humble, and below Humble sampling stations.

Originally the high phenol concentrations at the Humble Oil Refinery intake were not understood. Further study indicated the source of these high concentrations was seepage from the Humble property where high strength wastes were formerly disposed of underground.

The wastes from the Great Western Sugar Refinery were also checked for phenols during the same period when the river samples in Table 2 were collected. Yegen Ditch below Great Western indicated phenol from 0 to 7 ppb during the sampling. Water for the refinery is pumped from the Yellowstone River above Billings waste discharges.

Routine Sampling for Phenols

For the purpose of cataloging the trend in the level of phenolic compounds in the Yellowstone River between Laurel and Huntley, U.S. Geological Survey personnel were asked to collect water samples for analysis at monthly intervals. The USGS personnel graciously agreed to carry out this request and sampling was initiated during September 1953. The samples have been collected at three station, viz., upstream from the Laurel sewer and Farmers Union Central Exchange waste outfalls near the BL&I irrigation canal intake; at the U.S. Highway 87 bridge crossing in Billings; and at the U.S. Highway 10 crossing near Huntley (Figure 2). "Grab" samples of river water are taken in two and one-half liter glass bottles to which copper sulfate at the rate of one gram per liter has been added as a preservative to inhibit degradation of the phenolic compounds by the microbiota. The samples are shipped by railway express to the State Board of Health chemical laboratory and analyzed within 48 hours for phenolic compounds.

During the period September 30, 1953 to December 6, 1962, 94 samples from the Laurel and Billings stations and 93 samples from Huntley were analyzed. (Appendix A) The average concentrations of phenolic compounds at the three stations were 4.2 ppb at Laurel, 5.7 at Billings, and 10.0 at Huntley. These average concentrations of phenolic compounds are compared statistically later in this report, (page 49).

A close examination of the data suggests two points which were investigated further: (1) that a definite decrease in average "phenol" content of samples occurred since January, 1958; and (2) that seasonal averages varied considerably, (Table 3). With regard to the latter point, it can be statistically demonstrated that the rate of degradation of phenols is greatly reduced at a water temperature below 40° F. This indicates that phenolic materials can be carried much further downstream during periods of colder water temperature. The effect of the Billings oil refinery wastes on phenol levels in the Yellowstone River is also readily apparent.

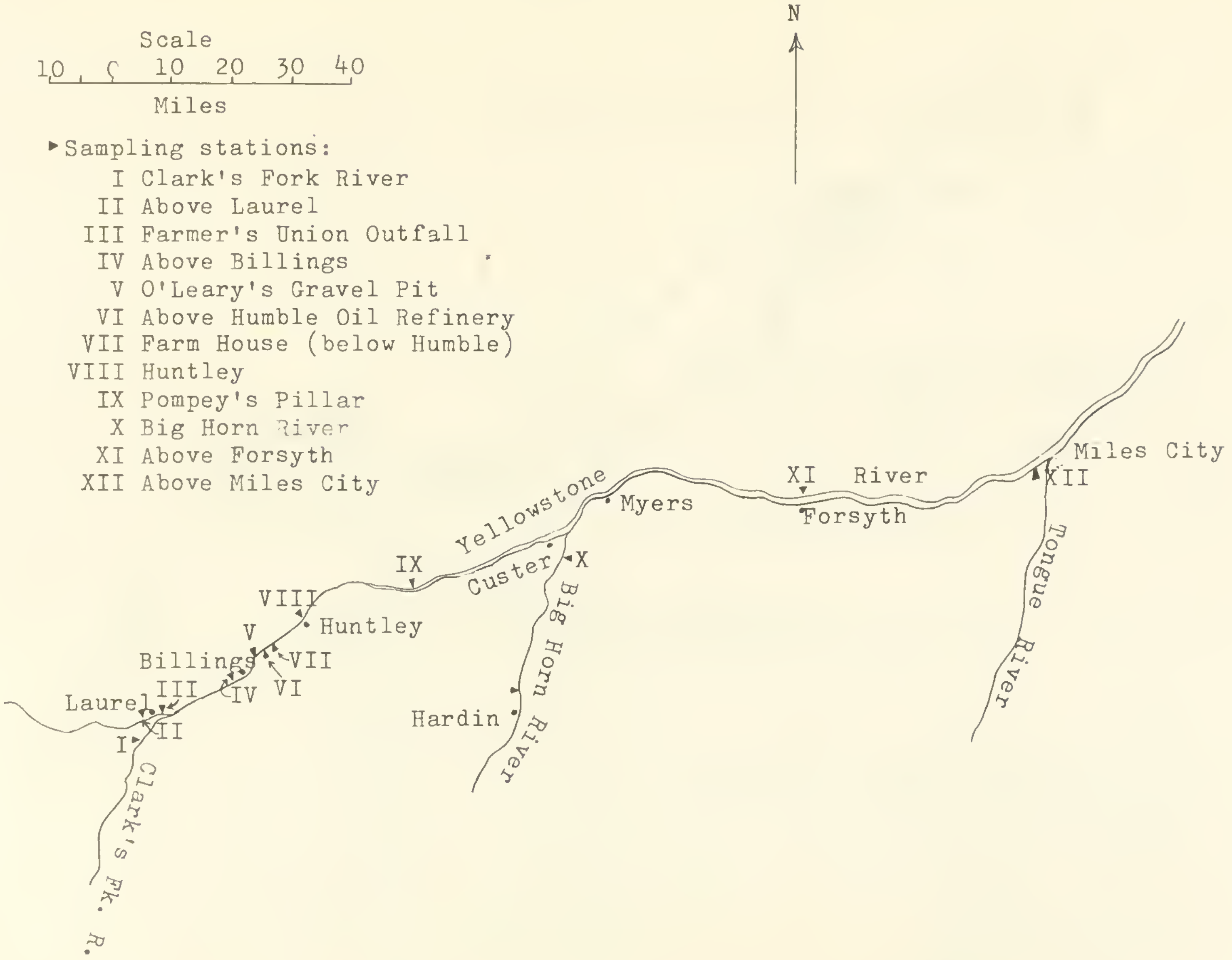


Figure 2. Map of the Yellowstone River pollution survey area.

Figure 3. Map of the Yellowstone River in Billings Area

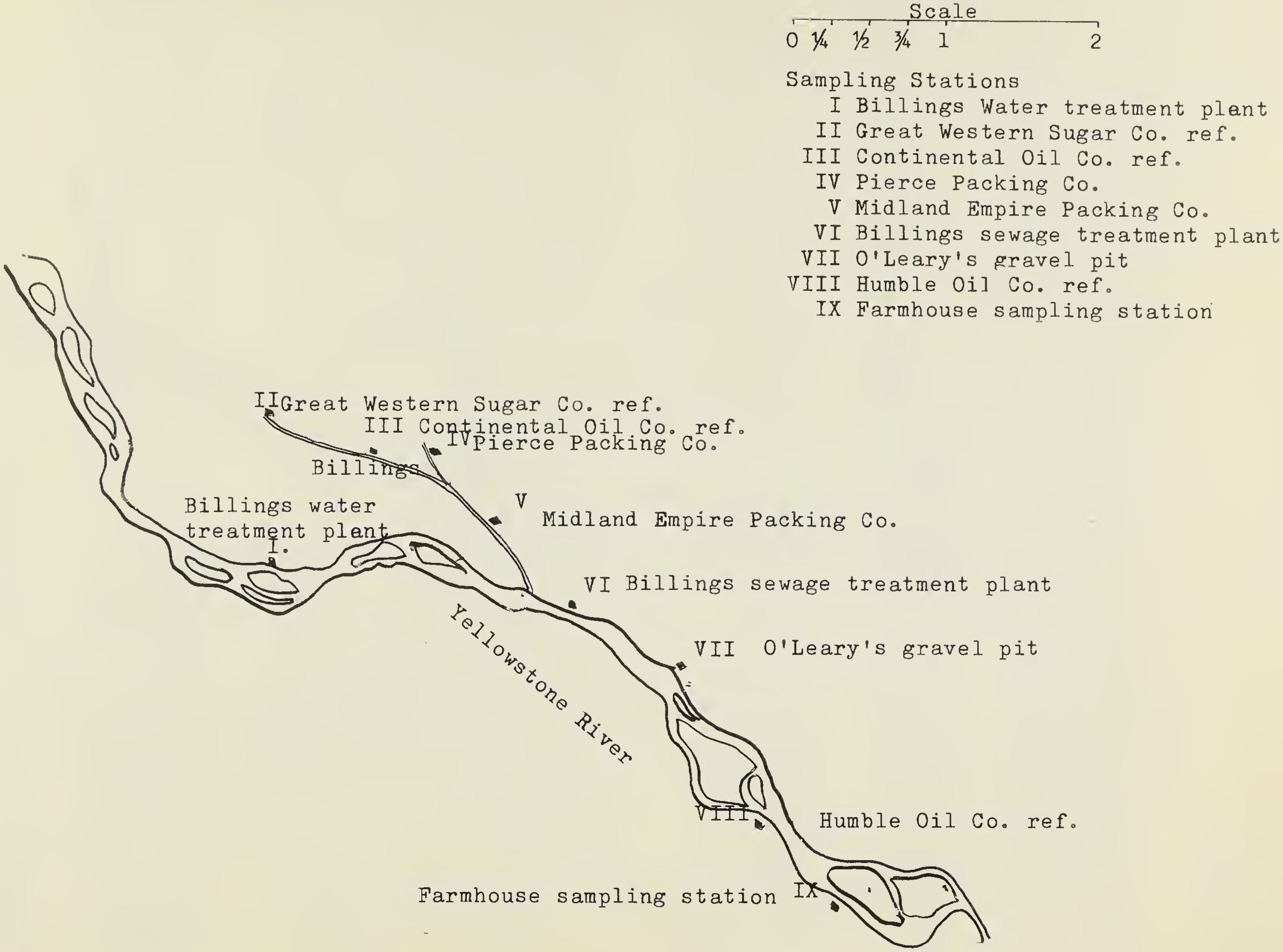

Scale
0 ¼ ½ ¾ 1 2
Sampling Stations
I Billings Water treatment plant
II Great Western Sugar Co. ref.
III Continental Oil Co. ref.
IV Pierce Packing Co.
V Midland Empire Packing Co.
VI Billings sewage treatment plant
VII O'Leary's gravel pit
VIII Humble Oil Co. ref.
IX Farmhouse sampling station
II Great Western Sugar Co. ref.
III Continental Oil Co. ref.
IV Pierce Packing Co.
Billings
Billings water treatment plant
I.
V Midland Empire Packing Co.
VI Billings sewage treatment plant
Yellowstone River
VII O'Leary's gravel pit
VIII Humble Oil Co. ref.
Farmhouse sampling station IX

TABLE 3

Seasonal averages of concentrations of phenolic compounds in Yellowstone River water samples 1953-62.

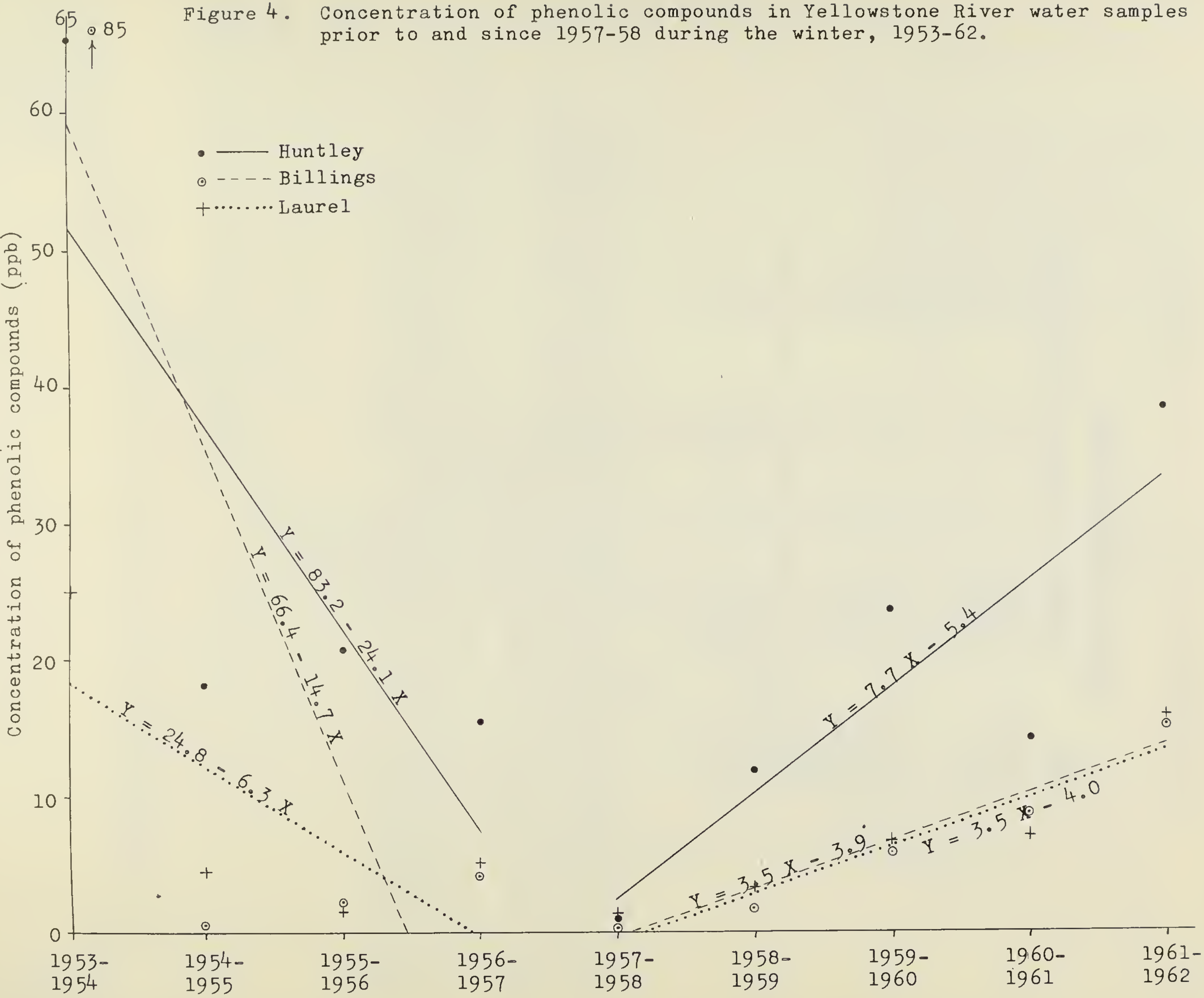
Phenolic Compounds (ppb)

Year	Season	Laurel	Billings	Huntley
Averages since 1953	Winter	7.6	13.9	23.0
	Spring	3.8	4.7	6.8
	Summer	3.0	2.5	2.7
	Fall	3.2	4.4	8.9
Averages before January 1958	Winter	9.0	23.0	29.7
	Spring	3.3	3.2	7.7
	Summer	5.7	4.6	3.8
	Fall	2.6	4.4	8.6
Averages since January 1958	Winter	4.6	6.6	17.7
	Spring	4.2	5.9	6.2
	Summer	0.9	0.9	1.8
	Fall	3.6	4.3	9.1

Concerning the decrease in average phenol content of water samples since 1958, especially during the winter season, the greatest change was recorded at Billings (Table 3). The level prior to 1958 was 23.0 ppb; since that time, the concentration has averaged 6.6 ppb. This reduction is attributed to the pollution abatement program carried out by the Farmers Union Central Exchange oil refinery at Laurel.

Using the analysis of variance test (Ostle, 1954), and again considering winter averages, the trend in levels of phenolic compounds (Figure 4) was treated statistically. Prior to 1958, the trend in phenol levels was steeply downward while, since 1958, the trend is significantly upward, especially at Huntley.

Figure 4. Concentration of phenolic compounds in Yellowstone River water samples prior to and since 1957-58 during the winter, 1953-62.



Oil

During the 1961 and the March, 1962 surveys, samples of refinery waste effluents were submitted for analysis of oil content to R. A. Taft, Sanitary Engineering Center of the U.S. Public Health Service, Cincinnati, Ohio. Waste samples were composited over a 10 to 24 hour period.

The lowest quantity of non-volatile oil (Table 4) was discharged to the river by Farmers Union Central Exchange (13-26 pounds per day). The Continental refinery values ranged from 68-450 pounds per day while 1,200 to 6,500 pounds of oil were discharged to the river system by the Humble refinery.

Oil deposits have been noted on the stream bottom at the "O'Leary's Gravel Pit" and "below Humble" stations. The significance of the greater amount of oil discharged by Humble becomes apparent when river bottom life is surveyed. These results are presented in greater detail later however, a brief description is in order here. The 1955 survey report (PHS, et al, 1956) cites "oil refinery waste products and tarry bottom deposits" as the cause for the "chronic dearth of bottom fauna below Billings". The same report describes bottom organisms as absent or rare below Laurel at that time. The 1960 survey report (Hayes, et al.) describes the section of river between Laurel and the mouth of Yegen drain as supporting a clean water biota. Though the numbers of organisms per unit area of river bottom are low and mostly comprised of pollution tolerant organisms, bottom fauna is now apparent below the entrance of Continental Oil refinery wastes into the Yellowstone River below Yegen Drain. Bottom fauna surveys conducted during November, 1962 and more recently (Oct. '63 & '64) have shown that very few, if any, bottom organisms are able to survive in the section of river immediately downstream from the Humble Oil waste discharge and do not reappear in normal number for several miles down river. The relatively great quantity of oily wastes in the Humble Oil refinery effluent precludes the existence of a normal bottom fauna community in the Yellowstone River until the waste is completely mixed with the river.

TABLE 4
Quantity of oil in refinery waste discharges to the Yellowstone River, 1955-62.

	Nov. 6-7, 1961	Dec. 6, 1961	Mar. 28, 1962
	Farmer's Union Central Exchange		
Volatile oil (ml/2 L.)	0.00	0.02	<0.02
Non-volatile oil (mg/L.)	5.3	6.6	11.9
(lb/day)	13	16	26
Waste flow (cfs)	0.45	0.45	0.41

Table 4 continued on next page

Table 4,continued

	Nov. 6-7, 1961	Dec. 6, 1961	Mar. 28, 1962
	Continental Oil Company		
Volatile oil (ml/2 L.)	0.10	0.4	0.35
Non-volatile oil			
(mg/L.)	39.1	44.9	184.8
(lb/day)	85	68	450
Waste flow (cfs)	0.40	0.28	0.45
	Humble Oil Company		
Volatile oil (ml/2 L.)	<0.02	0.05	<0.02
Non-volatile oil			
(mg/L.)	5.8	5.4	21.8
(lb/day)	1250	1250	6500
Waste flow (cfs)	40	43	55

Biochemical Oxygen Demand and Chemical Oxygen Demand

Other measurements of the strength and characteristics of organic wastes are the biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

The standard test in sanitary chemistry for determining organic material in a waste is the five day, 20° C. biochemical oxygen demand analysis. This measures oxygen depletion due to bacterial decomposition of organic material. Bacteria must depend upon non-living dissolved or suspended substances for their food supply. Practically any organic substance can be used as food by bacteria, and as a group, these organisms readily adapt themselves to the kinds of food available. The rate upon which the bacteria act depend on many things such as the kind and amount of organic material present, temperature, pH, light and other physical conditions. In the BOD analysis, a measured portion of the sample is incubated in a water of known oxygen concentration at 20° C. for five days. The amount of oxygen used is determined and the BOD computed.

The greater the BOD of a waste, the more bacteria that will be present in the stream below the waste discharge and a greater amount of oxygen will be used by the bacteria in their life processes. The oxygen needed by the bacteria to stabilize a waste can be provided in a treatment process or in the receiving waters of a stream.

For wastes such as petroleum refinery wastes, the BOD test is not considered a good measure of the effects of the wastes upon the stream as there are some organic compounds which are not readily stabilized by the bacteria. Therefore, the chemical oxygen demand test may also be used to measure the waste strength. In this method, measured amounts of potassium dichromate and sulfuric acid are added to a sample of waste. Most types of organic matter react with this mixture. The remaining dichromate which has not reacted is then measured and the COD computed.

Among the industries located in the Billings area which contribute organic loads to the river are the oil refineries. Significant reductions in BOD and COD have been affected by the oil refineries during the past seven years (Table 5 and Figures 5 & 6).

Other industries contributing large amounts of organic (and inorganic) wastes to the Yellowstone River in the Billings area include sugar beet refineries and meat packing plants. These industries are discussed in more detail in the latter part of this report. The treated sewage from the Laurel and Billings treatment plants also contains considerable organic material. Irrigation return flows add an additional amount.

TABLE 5

Biochemical oxygen demand (BOD) and oxygen consumed(COD) of wastes discharged to the Yellowstone River by oil refineries, 1955-62.

	Nov. 8-9 1955	Nov. 6-7 1961	Dec. 6 1961	Mar. 28 1962	Oct. 31 1962	Dec. 5 1962
	Farmers Union Central Exchange, Laurel					
BOD-Pounds per day	1130	12	53	39	32	70
Quantity in river after dilution (computed ppm)	0.07	0	0	0	0	0
Population equivalent	6600	70	310	230	190	410
COD-Pounds per day	1850	115	163	186		132

Table 5, continued

	Nov. 8-9 1955	Nov. 6-7 1961	Dec. 6 1961	Mar. 28 1962	Oct. 31 1962	Dec. 5 1962
	Continental Oil Company, Billings					
BOD- Pounds per day	732	495	135	950	200	60
Quantity in river after dilution (computed ppm)	0.04	0.02	0.01	0.04	0.01	0
Population equivalent	4200	2900	790	5600	1200	350
COD- Pounds per day	1060	1120	395	1850		132
	Humble Oil Company, Billings					
BOD- Pounds per day	5982		2760	1950	748	1000
Quantity in river after dilution (computed ppm)	0.32		0.15	0.08	0.04	0.06
Population equivalent	35200		16300	11500	4400	5900
COD- Pounds per day	26400	6900	4600	6300		2800

On an average, a person contributes 0.17 lb. BOD/day. Hence 0.17 lb BOD= 1 population equivalent.

Figure 5. Biochemical oxygen demand of oil refinery wastes discharged to the Yellowstone River, 1955-62.

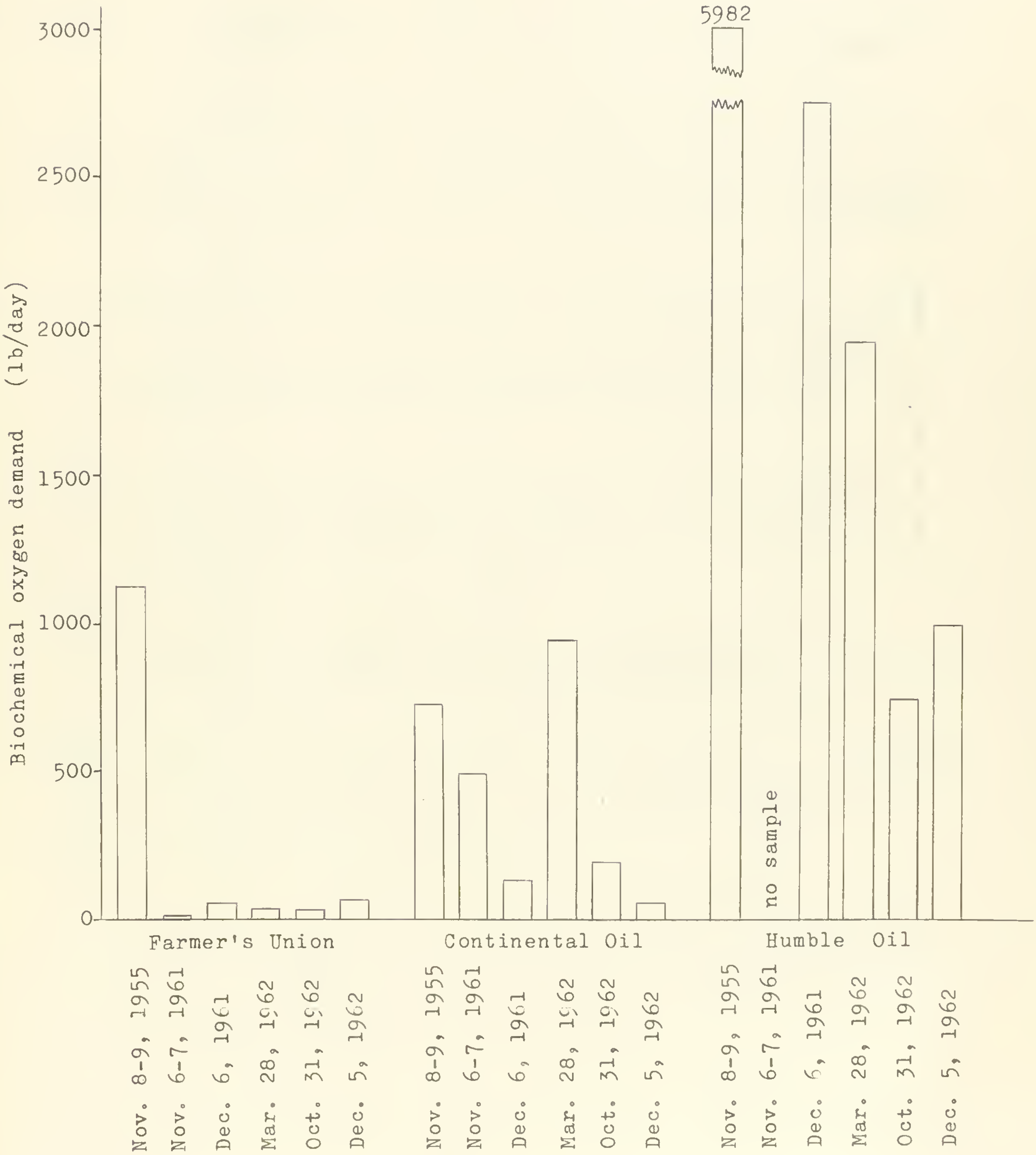
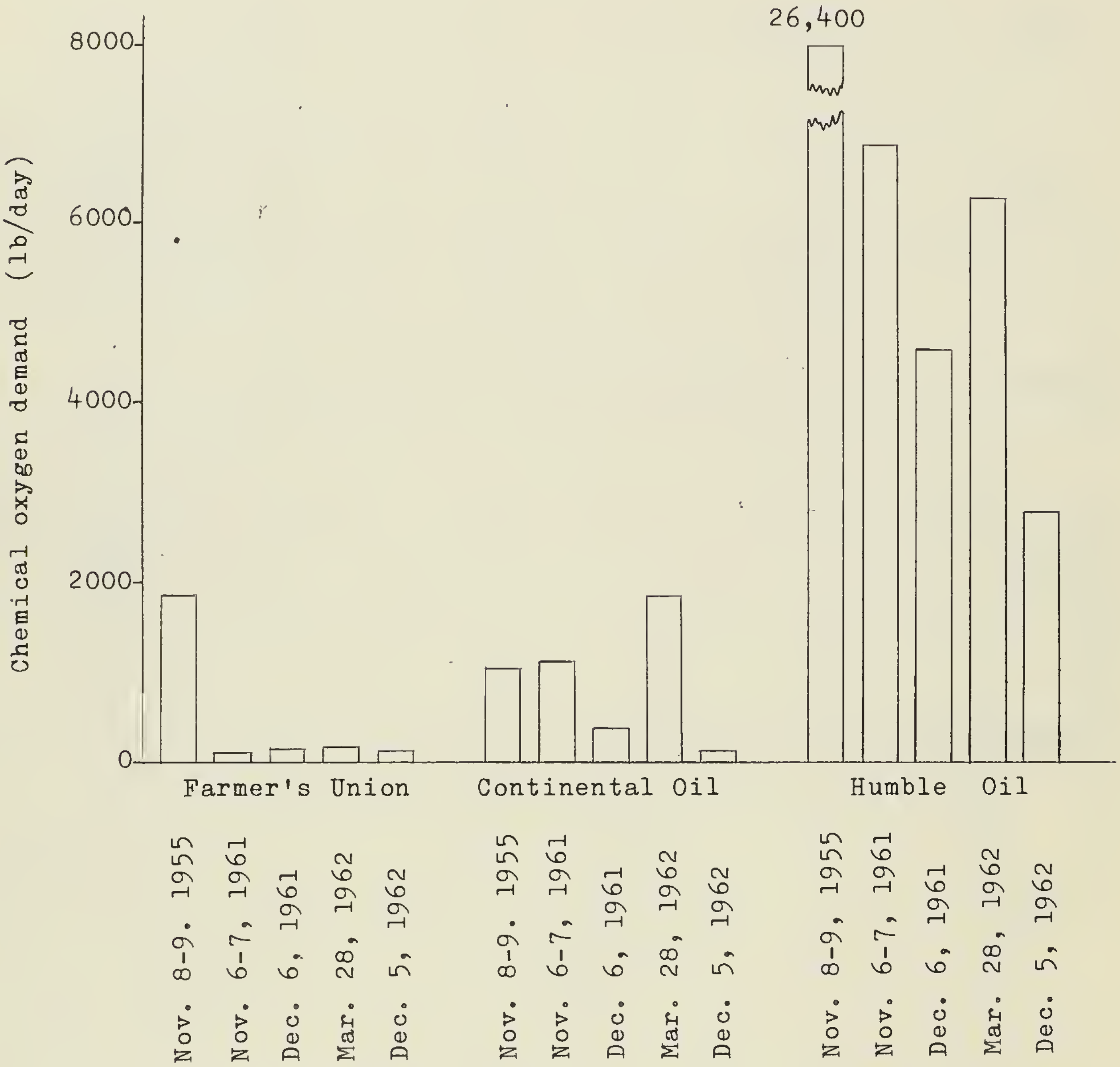


Figure 6.
Chemical oxygen demand of oil refinery wastes discharged to the Yellowstone River, 1955-62.



Sugar Beet Refineries

Sugar beets, when received at the plant, are passed over a screen for removal of soil and debris before they enter a channel referred to as a flume. Water flowing in the flume transports beets into the plant and acts as a wash to remove much of the loose soil from the beets. Readily settleable mud and debris is removed from the flume water and is hauled away. A mechanical trash collector operates in the flume to remove beet leaves, weeds, and trash. Beets are elevated by a wheel to a beet washer. Water is added to the washer continuously and overflows to waste with the flume water.

The beets are next sliced and pass to a diffuser. Sugar is extracted in the diffuser by passing hot water through the sliced beets. Fresh water is continuously added to the diffusion system so that the sliced beets which have been in the diffuser the longest are contacted with the freshest water first. Liquid drawn from the diffuser contains the sugar in solution and is called "juice".

The beet, which has had the sugar extracted and is now known as "pulp" is pressed and then dried. This pulp is a valuable animal feed.

The juice taken from the diffusers is chemically treated, settled and filtered to remove suspended matter and non-sugars. The filtered juice is then concentrated through multiple effect evaporators and again clarified.

Water is further evaporated from the juice in vacuum pans until crystallization of the sugar takes place and crystals have grown to the desired size. Sugar crystals are separated from liquid by centrifuging. The remaining liquid (molasses) is further treated and the final residue may be added to the pulp.

The principal wastes from a beet sugar refinery are the flume water, pulp screen water, pulp press water and the lime cake slurry from the chemical treatment. In addition to the above, the Great Western Sugar Refinery in Billings processes molasses. The waste from this process is then disposed of with the lime waste. All of the lime wastes at the factories are impounded. Before the use of pulp dryers, the pulp was merely discharged to silos until it was hauled away for animal feed. The drainage water from the silos was very high in organic matter. The use of pulp dryers has made possible the elimination of the pulp press and screen waters which are now returned to the sugar extraction process.

A comparison of wastes from the various sugar refineries are shown in Table 6 and Figures 7 and 8. The sugar beet season in the past has lasted from September or October to November or December. As the sugar beet season progresses, the strength of the wastes from the plants gradually increase. This is due to deterioration of the beet in storage. The highest BOD can be expected at the end of the season.

TABLE 6. Quantity of beets processed and some waste characteristics of sugar beet refineries in the Yellowstone River Drainage, 1955-62.

Date of survey	Beets processed (tons/day)	Waste flow (cfs)	BOD of waste		P.E. of waste x 1000	COD of waste (lb/day) x 1000	Suspended solids		River		
			(lb/day) x 1000	(lb/ton of beets)			(lb/day) x 1000	(lb/ton of beets)	flow (cfs)	BOD with waste (ppm computed)	S.S with waste (ppm computed)
Great Western Sugar Company, Billings											
Nov. 8-9, 1955	3640	30[1]	87.1	23.8	510		602	166	3550	4.5	31
Nov. 12-13, 1960	4300	28[1]	83.4	19.4	490		200	46	2450	6.3	15
Nov. 6-7, 1961	4425	33[1]	33.7	7.6	200				4710	1.3	
Dec. 6, 1961	4302	29[1]	64.7	15.0	380	79.6	516	120	3550	3.5	27
Oct. 31, 1962		34[1]	66.6	15.4[2]	433				3300	3.7	
Dec. 5, 1962		29[1]	45.1	10.6	265	46.7	220	50	3360	2.5	13
Holly Sugar Company, Hardin											
Nov. 10-11, 1955	1850	7.1	23.8	12.9	140		86.5		2400[3]	1.8[3]	
Dec. 5, 1961		7.6	25.0	13.5	147	23.2	74.3	40	3010[3]	1.6[3]	4.5[3]
Holly Sugar Company, Sidney											
Nov. 10-11, 1955	1961	11	26.6	13.6	157		216	110	6440	0.8	19
1961 average	2425										

[1] flow as measured in Yegen Ditch. Part of flow is discharge from storm sewers in Billings. BOD and suspended solids content of storm sewage is negligible.

[2] Steffens waste discharge to Yegen Ditch instead of lime pond as a result of a pump failure.

[3] Big Horn River

Figure 7. Biochemical oxygen demand of sugar beet wastes discharged to the Yellowstone River drainage system, 1955-62.

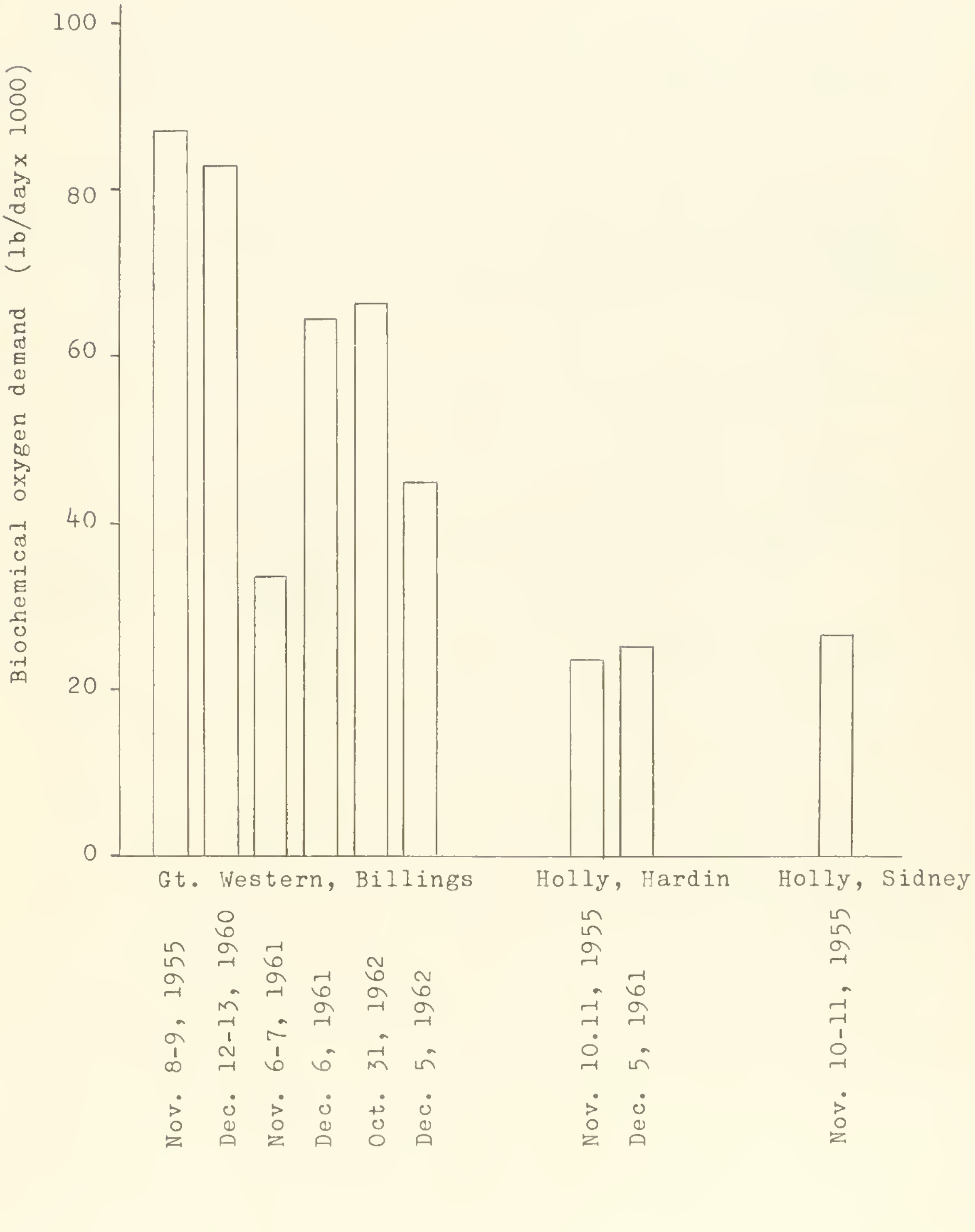
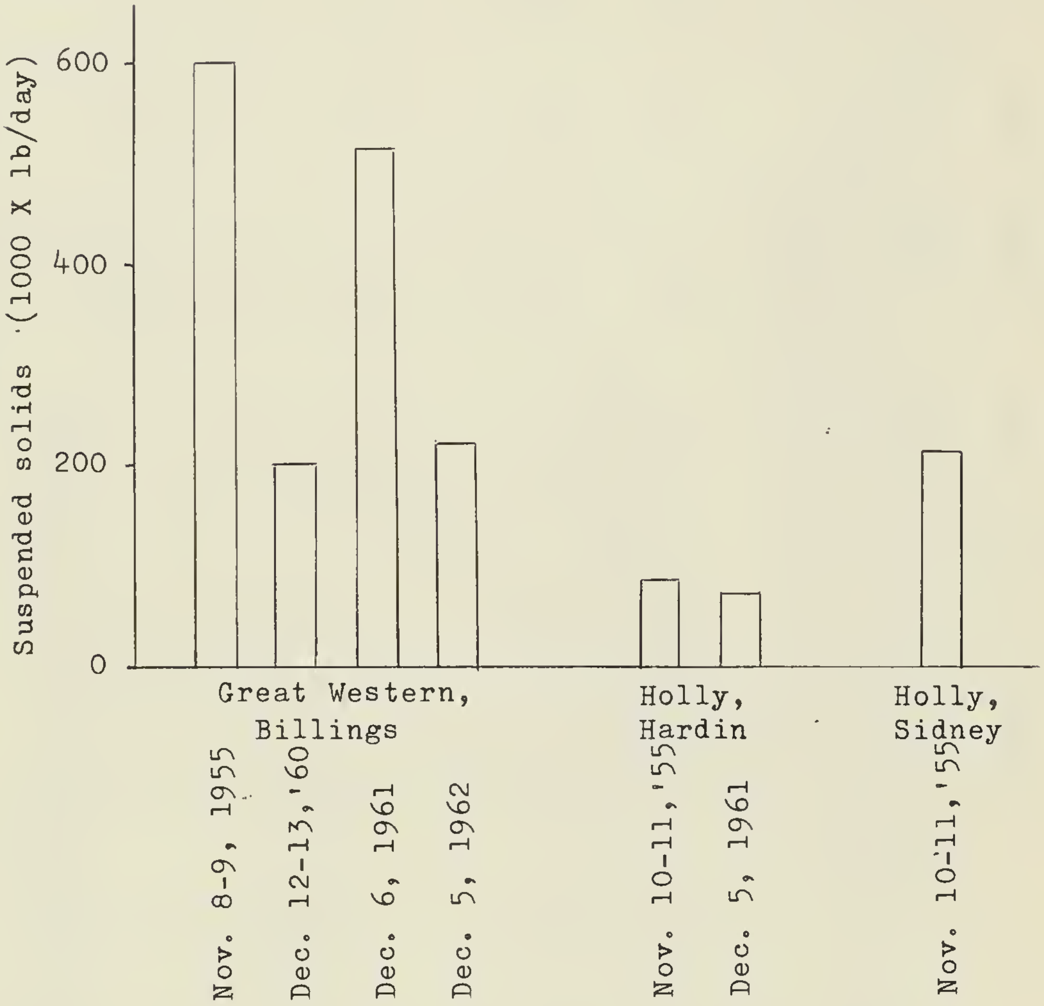


Figure 8. Quantity of suspended solids discharged to the Yellowstone River drainage system by sugar beet refineries, 1955-62.



The principle recommendations made to the sugar beet refineries in 1955 were : "Virtual elimination of settleable and floatable solids, and reduce 5-day 20° C BOD to not more than eight pounds per ton of beets sliced." To date, though some reduction of BOD has been affected, the proposed goal has not been reached by any of the refineries. Large quantities of settleable and floating solids are still discharged with the wastes.

Recently, improved equipment for beet receiving has been provided by the companies to reduce the dirt and trash reaching the refineries. The Great Western Sugar Company is providing screening facilities for flume waste water for removal of the larger solids. Settling facilities would remove most of the suspended solids along with about 25% of the BOD.

Meat Packing Plants

There are two major meat packing plants located at Billings. The Midland Empire Packing Company and Pierce Packing Company discharge their untreated wastes to the Yegen Drain Ditch which flows into the Yellowstone River.

The first step in processing is killing and bleeding of the animal. The hides are then removed from the carcasses except in the case of hogs. The latter are immersed in boiling water and the hair is removed by scraping. The viscera are then removed and the carcass further processed. Except for the paunch manure, the viscera are all used in the plant for various by-products. If not used for edible products, portions of the animal will be rendered for recovery of grease and tankage.

The principal wastes from meat packing are blood, paunch manure, rendering waste and numerous scraps and greasy materials that find their way to the sewer during processing.

The blood from the killing floor is collected by both packing companies, and, in the case of Pierce Packing, this collected blood is dried and sold. Midland Packing at the last report was rendering for tankage about 75 percent of the blood and wasting the remainder to the river.

Separate disposal of paunch manure is commonly practiced by the industry. At the Midland plant, the paunch manure is collected and hauled away. The Pierce Packing Company merely discharges it to the sewer.

Even though grease traps are provided, much grease has been noted in Yegen Drain Ditch and the Yellowstone River below the ditch, indicating that better grease removal facilities are needed. (Table 7 and Figure 9 indicate a comparison of 1955 waste loads with 1962 waste loads.)

After the 1955 study, it was recommended to both companies that they separately collect and dispose of blood and paunch manure, provide effective grease removal, effectively screen all wastes except sanitary sewage and make appropriate arrangements as necessary for discharge of residual plant wastes to municipal sewers.

The Pierce Packing Company is in the process of carrying out the 1955 recommendations. Pre-treatment facilities are being constructed so that connection to the City of Billings sewer system can be made.

The Midland Empire Packing Company has submitted preliminary plans for their waste treatment plant to be located adjacent to the packing plant. It is believed that Midland will begin construction of these facilities during 1964.

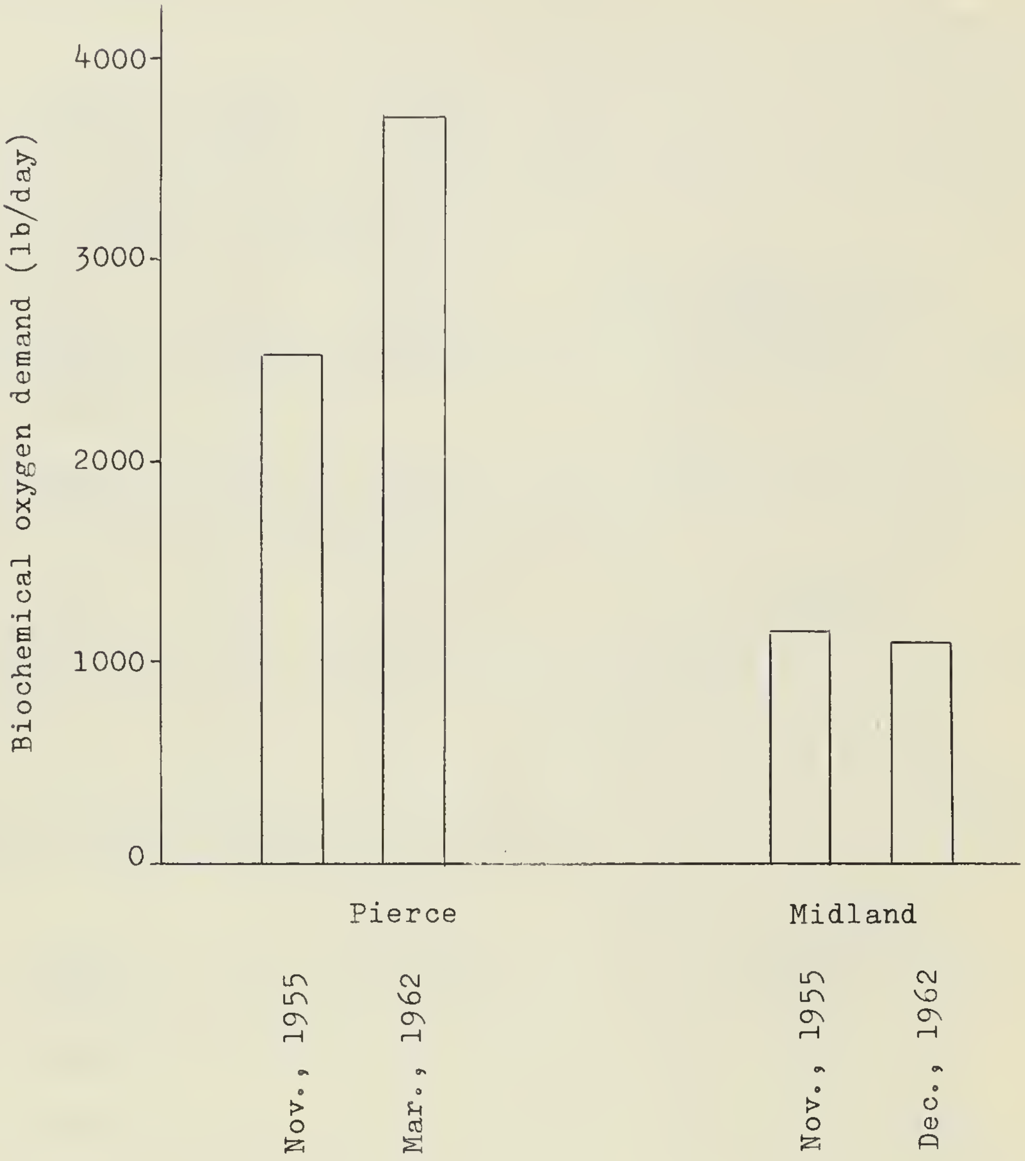
Table 7. Number of animals slaughtered, waste flow and BOD of meat packing wastes in Billings, 1955-62.

	Nov. 1955	Mar. 1962	Dec. 1962
	Pierce Packing Company		
Animals slaughtered			
Hogs/week	2100	540[1]	2800
Cattle/week	280	120[1]	375
Waste flow (cfs)	-	0.41	0.4
River flow (cfs)	3500	4450	3000
BOD			
(lb/day)	2520	3700	3500[2]
(ppm in river; computed)	0.13	0.15	0.22
Population equivalent (x 1000)	16.5	22.0	21.0[2]
	Midland Empire Packing Company		
Animals slaughtered			
Hogs/week	625		690
Cattle/week	250		270
Waste flow (cfs)	-		0.15
River flow (cfs)	3500		3000
BOD			
(lb/day)	1150		1100[2]
(ppm in river; computed)	0.06		0.07
Population equivalent (x 1000)	6.8		6.5[2]

[1] number for day of sampling

[2] estimated

Figure 9. Biochemical oxygen demand of meat packing wastes discharged to the Yellowstone River at Billings, 1955 and 1962.



Domestic Sewage

On the basis of population equivalent (PE) the contribution of organic matter to the Yellowstone and Big Horn Rivers by municipal sewerage systems has remained about the same in the period 1955 to the present. Several communities have provided treatment in the interim. However, this has been mostly offset by the increase of the sewered population in the Billings area. Billings had primary treatment before 1955 and is presently adding chlorination facilities to its treatment process.

Table 8 indicates the sewage treatment provided by the various communities on the Yellowstone and Big Horn rivers. As can be seen, the communities have done exceptionally well in providing sewage treatment. Gardiner, Hysham, Terry, Highland Park (Glendive), and Fairview have been requested to provide new treatment facilities. Terry's facilities are under construction.

Table 8. Population equivalent of treated sewage discharged to the Yellowstone and Big Horn Rivers, 1955 and 1962.

Municipality	Miles above river mouth	Type of treatment	Estimated Population Equivalent of Waste		
			before treatment	after treatment	
			1962	1962	1955
Gardiner	535	S	400	350	300
Livingston	476	P + Cl	7400	4450	6800
Big Timber	436-0.8	L	1400	250	1000
Columbus	394	L	1000	200	900
Laurel	367	P + Cl	5300	3700	2800
Billings	345	P + Cl	65000	41000	16500
Worden	322	L	200	20	NS
Hardin	279-40	L	2500	ND	1400
Hysham	260	S	275	ND-r	200
Forsyth	230	L	2000	400	1500
Miles City	179	L	9500	ND	9500
Terry	134	S	1000	750	750
West Glendive					
(RID No. 10)	91	L	1000	200	NS
(Highland Park)	90	I	300	250	200
Glendive	89-1	L	5060	ND	5000
Sidney	30	L	5000	1000	4000
Fairview	-	I	1200	900	900
		Totals	108535	54470	51750
		BOD (pounds)	18400	9100	8800

[1] one P.E. = 0.17 lb BOD

[2] Big Horn River

ND = no discharge as yet; ND-r = no discharge to river; NS = no sewer system; S = septic tank; I = Imhoff tank; P = primary treatment plant; L = lagoon; Cl = chlorination

Up to this point, the report has dealt mainly with a survey of wastes discharged to the Yellowstone River. The remainder of the report concerns itself with the effects of these wastes upon the ecology of the river.

Stream Ecology

In conjunction with the stream survey, collections of biological components include bottom fauna, plankton, and attached algae. Bottom fauna include the benthic (bottom-dwelling) macro-invertebrates (immature aquatic insects, snails, aquatic earthworms, roundworms, clams, etc.) and vertebrates (minnows and young of larger fish) of a body of water. Plankton is the assemblage of plant and animal life, mostly microscopic in size, made up of diatoms, algae, micro-crustacea, rotifers, and so forth, suspended in the water. Attached algae is the assemblage of rootless plants growing upon the free surfaces of objects submerged in water. This component of the ecosystem of a stream imparts the slimy and slippery characteristics to stream bottomsso well known to anglers during late summer. Variations in the organic loading of a body of water impart a correspondingly direct variation in the quantity of plankton and attached algae. This in turn may be reflected in the numbers and kinds of organisms in the bottom fauna. Various groups of aquatic vertebrates and invertebrates are generally represented in any bottom collection. Under "clean-water" stream conditions more species of organisms are present and generally fewer individuals of any one species. Under conditions of organic pollution the number of different species present decreases drastically and generally an increase in individuals of certain kinds is apparent. In addition, and most important, certain organisms are adversely affected by pollutants; others are very tolerant; and still others are facultative, i.e. they can exist to a degree under both clean and polluted water conditions. Further in a well balanced community of benthic (bottom dwelling) organisms, taxonomic groups of animals and plants belonging to each of the sensitive, tolerant, and faculative divisions are normally present. As the pollution load increases, the sensitive organisms disappear and the faculative-tolerant groups tend to predominate. Under conditions of gross pollution, the more tolerant flora and fauna are present.

Among the invertebrate benthos, it is universally agreed that the Plecoptera (stoneflies, such as the "salmon fly") Ephemeroptera (mayflies), and Trichoptera (caddisflies or "rockworms") are very intolerant to pollution. Among the bottom dwelling fishes Cottus spp. (sculpins) have been found to be very intolerant to even light loads of pollution.

The orders of aquatic invertebrates included in the tolerant or facultative division are the Pulmonata (snails; mostly the air breathing Physa spp.), Coleoptera (beetles), Diptera (midges, black flies, snipe flies crane flies, etc.) and Hemiptera (water striders and water boatman). The occassionally collected species of the Class Turbellaria (Planeria sp.), the Sub-class, Arachnida (aquatic mites), and the order Amphipoda (side swimmers), are placed in the tolerant-facultative group. Phylum Annelida (earthworms) was represented in the collections by the highly tolerant oligochaets (aquatic earthworms) Tubifex sp., the less tolerant Lumbriculus sp., and the apparently facultative leech (Order, Hirudinea). A few free-living (non-parasitic) nematodes (roundworms) were collected and are placed in the facultative group.

A minnow (Rhinichthys cataractae), commonly called dace, is quite abundant in the Yellowstone River and has proven to be very tolerant to polluted water conditions.

Methods of collection and analysis of biological samples were conducted according to "Standard Methods" (APHA, et al, 1960) in all cases where standardized methods have been available. The Surber, square-foot method of bottom sampling has been employed with two or three square feet of stream bottom being covered at each station. Limitations on time available for stream survey and severe ice conditions during the winter months have hampered bottom sampling during this survey.

Permanent stream sampling stations were located at the Laurel and Billings water treatment plants, O'Leary's Gravel Pit, Huntley, Pompey's Pillar and the Farm House. Also near the mouth of the Clark's Fork River. (Figure 3).

Plankton and periphyton samples were collected during the course of the stream survey however, lack of time for analyses of these samples has prevented further investigation of this component of the aquatic community.

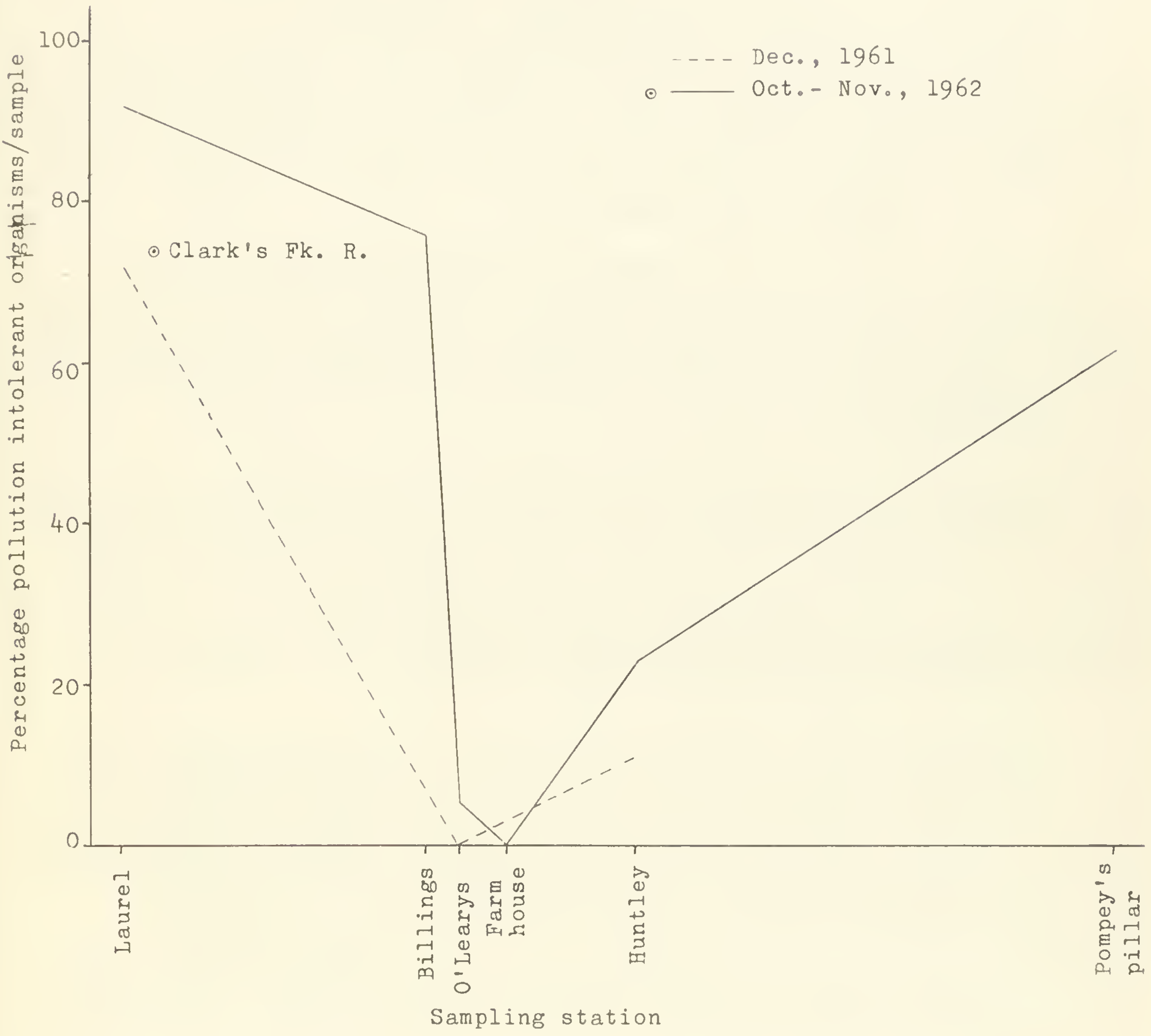
Analysis of collections of attached algae taken during late August, 1961 were completed and the predominant alga was identified as Cladophora fracta. The most common alga during 1955 was reported as Caladophora spp. also. A very luxuriant growth of this alga was apparent during the summer of 1961 as a result of the very low flow and accompanying high water temperatures combined with a large quantity of organic enrichment from municipal and industrial waste discharge including irrigation waste water. A "musty" odor in the municipal water supply reported by the Laurel water department during early September, 1961 was undoubtedly caused by the profuse growth of Cladophora which developed during the summer.

With regards to collection of bottom fauna during 1955, polluted conditions were apparent from Laurel to at least the mouth of the Big Horn River. The 1960 survey indicates gross pollution below Billings (centered near Pompey's Pillar) with the major change from 1955 being a trend toward recovery to clean water conditions below Laurel and above Billings. Bottom fauna sampling (Table 9) during this investigation substantiates the 1960 findings. Only three stations were sampled during the December, 1961 survey since ice conditions prohibited collections at other stations. The more complete sampling during October-November, 1962 describes a typical response of bottom organisms to polluted water conditions (Figure 10). Again a high percentage of pollution intolerant organisms were found in the section of river between Laurel and Billings. The great improvement in conditions since 1955 is attributed to the installation of adequate treatment facilities by the Farmer's Union Central Exchange Oil Refinery and the Northern Pacific Railway shops. Conditions of gross pollution however, still exist below the mouth of the Yegen Drain (O'Leary's Gravel Pit, Figure 10). The absence or rarity of benthic fauna in the river from three miles below Laurel to Huntley reported by the 1955 survey was attributed to the toxicity of oil refinery effluents. Some improvement is apparent in this section of the river along the north bank since pollution tolerant organisms are present below the Yegen Drain and at Huntley. However, conditions of high toxicity are still apparent along the south shore of the river below the discharge of the Humble Oil Refinery wastes at the Farmhouse sampling station (Table 9). A more

Table 9. Bottom fauna from the Yellowstone River in the Laurel - Billings - Huntley area, Dec., 1961 and Oct. - Nov., 1962.

Sampling station	Date	Pollution sensitive organisms				Pollution tolerant organisms				Percent sensitive organisms
		Ephem.	Plec.	Tric.	Total	Tubif.	Dip.	Other	Total	
Above Laurel	12/4/61	18	13	39	70	1	24	2	27	72
	10/29/62	98	33	221	352	0	31	0	31	92
Clark's Fork R.	10/30/62	51	0	76	127	0	45	0	45	74
Above Billings	10/30/62	69	1	110	180	0	56	1	57	76
O'Leary's Gravel Pit	12/6/61	0	0	0	0	400	14	1	415	0
	10/31/62	1	0	0	1	17	2	1	20	5
Farm House	11/1/62	0	0	0	0	0	0	0	0	0
Huntley	12/6/61	1	17	0	18	65	74	3	142	11
	10/30/62	9	1	0	10	11	22	1	34	23
Pompey's Pillar	10/30/62	13	3	29	45	1	26	0	27	62

Figure 10. Percent of pollution intolerant organisms in bottom fauna samples from the Yellowstone River drainage in the Billings-Laurel area Dec., 1961 and Oct.-Nov., 1962.



recent survey conducted October 2-3, 1963 further substantiates this statement. An excerpt from the field investigation report of this survey dated November 14, 1963 is an follows: "On the south (right) bank of the river, the section of stream practically void of bottom fauna as a result of toxicants associated with the Humble Oil Company waste effluent, extends for at least three miles downstream from the refinery waste discharge. Below this point, the river appears to have been fairly well mixed with Yegen Ditch wastes as evidenced by the recovery of sugar beet wastes on the right bank. Further evidence of the mixing appears just above the Huntley diversion dam where algae on the left bank was an unhealthy, dark rust color. Since the algal growth was a healthy green above the Humble Oil waste discharge, it is probable that algal growths along both sides of the river immediately above the dam were suffering from the effects of the Humble Oil company discharge."

"The results of this survey further substantiate prior findings that the toxicity of the Humble Oil Refinery wastes precludes or inhibits the existence of bottom fauna in the river from the point of entrance of the wastes into the stream to a point about three miles downstream.....The toxicity of Humble Oil Refinery wastes retards the forces of "natural purification" provided by aquatic organisms and substantially increases the length of the polluted section of the river."

A note of caution is in order here regarding the dynamics of bottom dwelling organisms. High-water dilution and low water temperatures will permit the reinvasion of stream bottom areas by aquatic organisms and at times of the year when conditions of high water and low temperatures are prevalent, bottom dwelling organisms may be found in sections of river void of these animals during the low stream flow, high temperature period of the year. Therefore, in the stream section immediately downstream from the Humble Oil Refinery waste outfall, bottom dwelling invertebrates could probably be expected to exist during the period of high water runoff in the spring.

In concluding this section on the biological survey, it is noted that there has been a return to clean-water conditions in the Yellowstone River between Laurel and Billings since 1955, but no improvement in stream ecology below Billings has been realized as indicated by the 1960 study and this survey. The toxic components of oil refinery wastes still exert a detrimental effect upon the bottom dwelling organisms below the Humble Oil refinery. Production of attached algae by the Yellowstone River is increased to nuisance proportions by the discharge of organic wastes and probably contributes to taste and odor problems in downstream water supplies. The "musty" taste and odor of Laurel water during early September, 1961 probably resulted from the luxuriant growth of attached algae prevalent in the stream during the summer of 1961.

Chemical and Physical Characteristics

In connection with the stream and wastes survey, certain physical and chemical(or biochemical) analysis of river water samples were conducted. Some determinations were made in the field and others on water samples returned to the Board of Health Laboratory in Helena.

Physical and chemical determinations conducted in the field were dissolved oxygen, pH, alkalinity, hardness, turbidity, and chlorides. Water temperatures were recorded in connection with dissolved oxygen analyses. Water samples for sulphates, nitrates, phosphates, filterable residue at 103° C., loss on ignition at 600° C., bio-chemical oxygen demand and chemical oxygen demand were returned to the laboratory and analyzed there. In order to minimize bacterial degradation, water samples for chemical analyses returned to the laboratory were placed in coolers with ice upon collection, returned to Helena, and refrigerated there until analyzed.

All chemical determinations made during this survey (Appendix B) were conducted according to "Standard Methods" (APHA, et al, 1960).

BOD and Dissolved Oxygen (DO)

Dissolved oxygen analyses were conducted by the Alsterberg modification of the Winkler method (APHA, et al, 1960) and values were converted to percent saturation at ambient temperature and corrected for altitude above sea level. Altitudes of the sampling sites have been taken from maps, (or estimated from altitudes taken from maps) and the factor for correcting the concentration of dissolved oxygen for altitude (APHA, et al, 1960) was computed.

In addition to conducting biochemical oxygen demand on water samples, river water samples were incubated and BOD's determined. (Table 10)

Table 10. BOD of Yellowstone River water samples, 1961-62.

Station	Mileage from Laurel	BOD (ppm) Dec. 6 1961	Mar. 28 1962	Oct. 31 1962	Dec. 5 1962
Above Laurel	0	1.2	3.0	0.7	0.6
Above Billings	20.8	0.9	2.4	1.0	0.7
O'Leary's G. P.	22.1	15.0	2.2	10.8	12.8
Above Humble	23.3	1.5	1.9	1.5	1.3
Below Humble	24.5	3.0	2.5	6.5	2.1
Huntley	33.4	3.4	1.8	3.6	2.0
Added to river (computed ppm)		4.6	0.7	4.5	3.3
River flow (cfs)		3550	4450	3300	3360

The higher BOD values noted on March 28, 1962 at Laurel and Billings are probably due to the heavy rainstorm which occurred on the previous evening and which may have washed considerable organic material into the river.

The reduction of BOD in the river between Billings and Huntley was computed by adding the calculated BOD added to the river at Billings to the amount of BOD found in the river above the waste discharges and then subtracting the amount of BOD found in the river at Huntley. This reduction amounted to about 40 per cent during October, November, and December when the sugar beet refinery is operating. It is believed that, with the colder river temperatures, this reduction is primarily due to settling of the heavier suspended solids on the stream bottom.

The greatest source of organic material (as measured by BOD) added to the river, is Great Western Sugar Company. Fortunately the refinery operates during a time of colder water temperatures and their highest BOD would normally be reached during the end of the processing season (December) when the river water temperature is the lowest.

Dr. E. R. Dodge, Professor, Civil Engineering at Montana State College used a computer to predict oxygen values at different times of the year at selected points below Billings. When polluted water is exposed to air, there is an absorption of oxygen from the air (reoxygenation) to take the place of the dissolved oxygen that is consumed to supply the biological demand (deoxygenation). In the computations the reoxygenation and deoxygenation constants were estimated. From the computations, dissolved oxygen did not appear to be a critical factor in Yellowstone River pollution at the present time. However, the computations do not take into consideration biological growths which occur below points of organic enrichment such as sewage and other waste discharges. Photosynthesis by these organisms provides oxygen in excess of respiration needs during the daylight hours. During the night, respiration may lower dissolved oxygen values much below that indicated by the dissolved oxygen computations.

The 1955 report (U. S. Public Health Service, et al) states that supersaturation of dissolved oxygen occured at all sampling sites during 1952 and at only two stations during the 1955 survey. This is understandable since the 1952 work was done during August and September and the 1955 study was conducted during November after photosynthesis had decreased. Apparently all 1952 and 1955 samples were collected during the day, thus, low saturation occurring at night was not measured. Saturation values varied from 85 to 95 percent during November, 1955 except the section of river affected by Yegen Drain wastes. The latter dissolved oxygen value represented 43 percent saturation. Daytime dissolved oxygen values during the 1960 study period indicated supersaturation around Worden and a low saturation value below Yegen Drain, both as a result of organic enrichment from the Billings area. Twenty-four hour dissolved oxygen analysis conducted during the 1960 study period below Billings indicates the dissolved oxygen values occurred around 4:00 P.M. with a minimum concentration of dissolved oxygen as established by the Water Pollution Control Council.

An overnight dissolved oxygen analysis (Figure 11) conducted August 31 to September 1, 1961 at Pompey's Pillar sampling site shows a depression in dissolved oxygen saturation to 68 percent around 5:00 A.M. This is in close agreement with the 1960 findings and indicates no improvement in stream conditions since that time.

Daytime dissolved oxygen saturation values taken during this survey (Figure 12) indicate that a dissolved oxygen sag occurs near Huntley.

Figure 11. Overnight variation in percent saturation of dissolved oxygen of the Yellowstone River at Pompey's Pillar, Aug. 31-Sept.1, 1961.

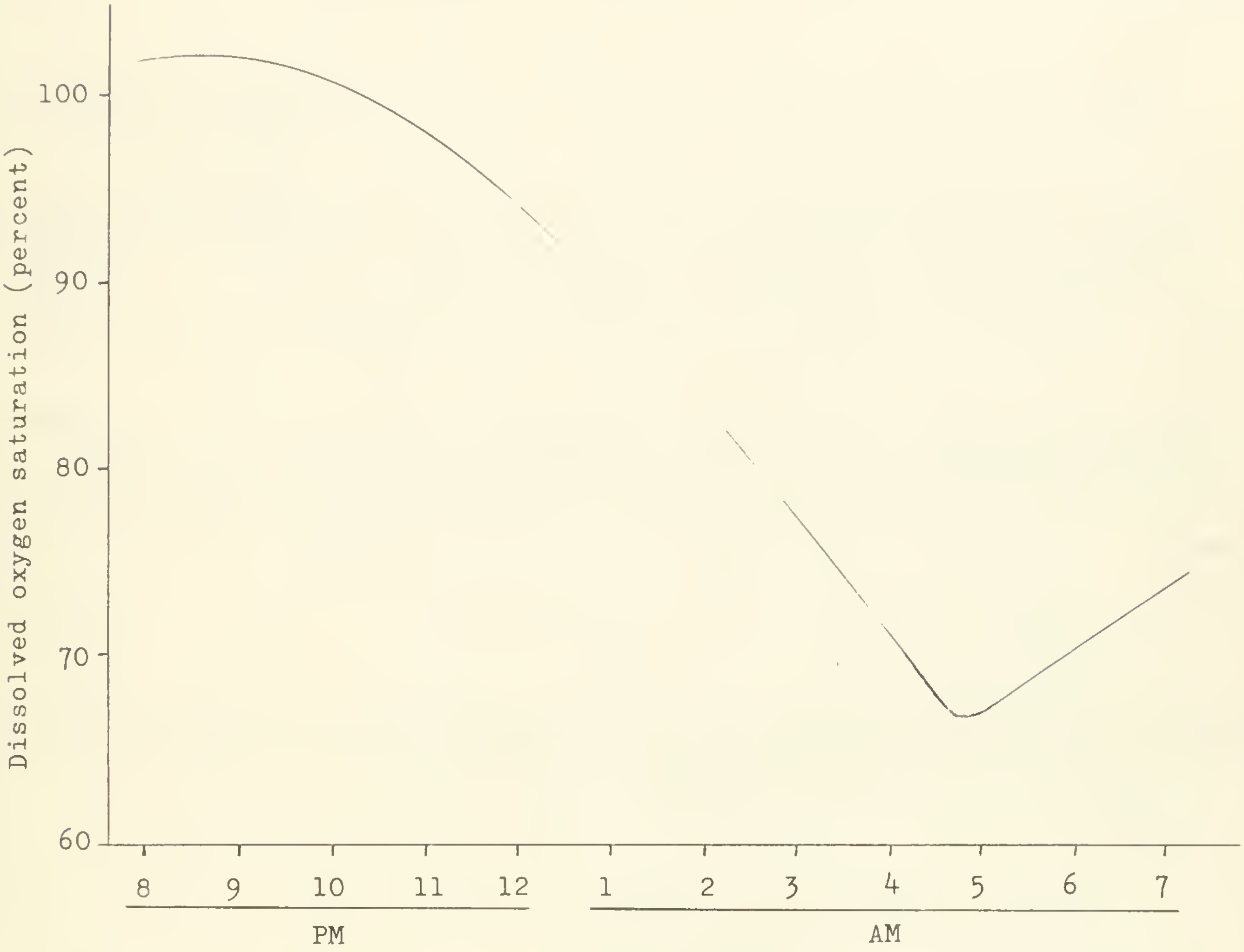
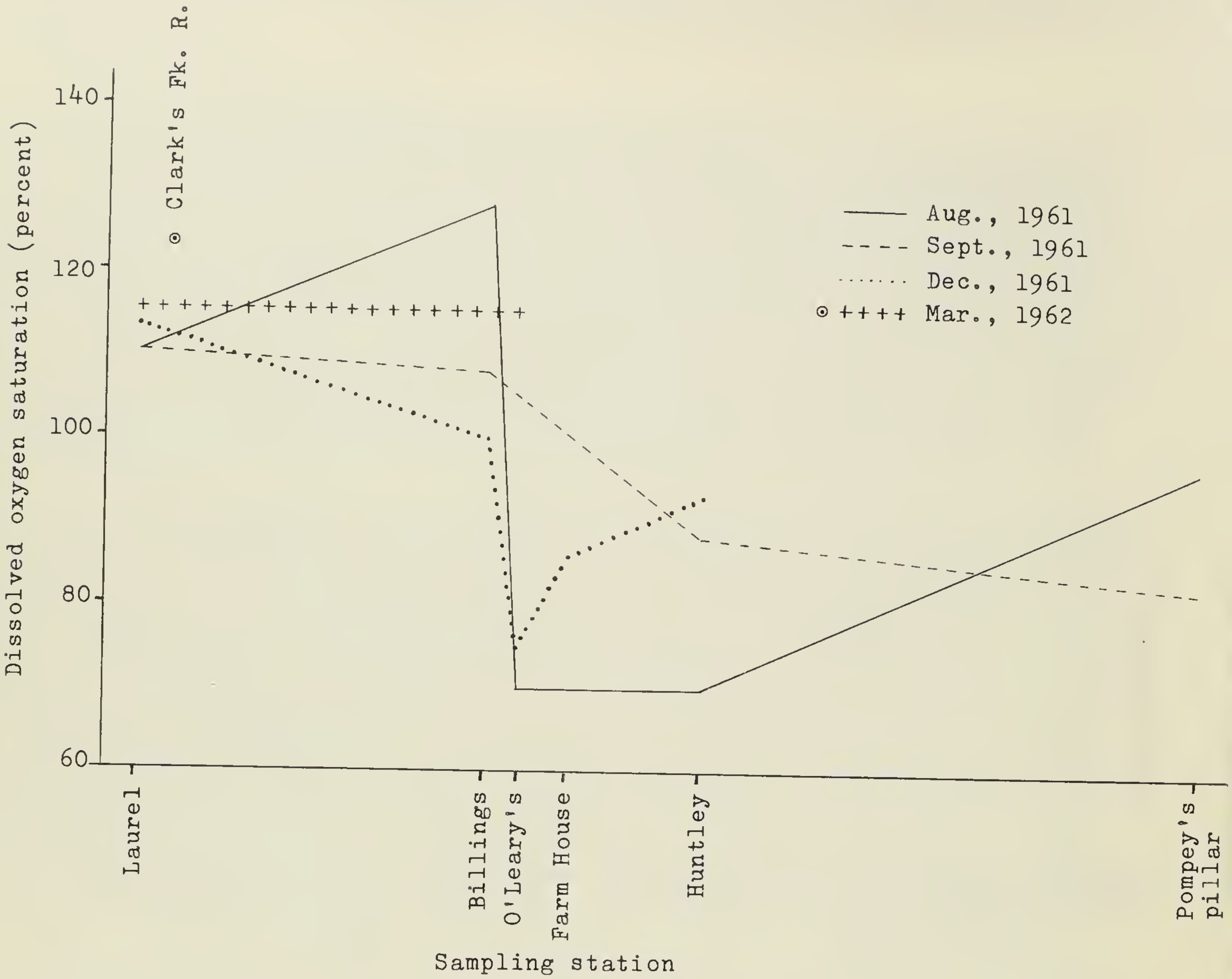


Figure 12. Daytime dissolved oxygen saturation values of the Yellowstone River in the Laurel-Billings area Aug.-Dec., 1961 and Mar., 1962.



pH: Hydrogen ion concentration (pH) ranged from 7.8 at Laurel to 9.2 at Billings (Appendix B). The upper limit of 8.5 established as the objective for pH by the Water Pollution Control Council was exceeded at Laurel, Billings, Huntley and Pompey's Pillar during August, 1961 and reached at Billings and the Farm House sampling stations during November, 1961.

Alkalinity:* Total alkalinity increased progressively from Laurel to Pompey's Pillar with the lowest reading of 110 ppm at Laurel during March, 1962. A maximum of 317 ppm was recorded at Pompey's Pillar during November, 1961.

Hardness: Hardness also increased at downstream stations. A low of 140 ppm (as $CaCO_3$) was recorded at Laurel in November, 1961 and a high of 320 ppm was found at Pompey's Pillar in September, 1961 (Appendix B). On the basis of U. S. Geological Survey Standards of water for domestic use hardness classification, the Yellowstone River in the Billings area would be classified as moderately hard to hard.

Turbidity: Turbidity ranged from a low of less than 7 ppm at Laurel during December, 1961 to a maximum of 550 ppm at Pompey's Pillar during September, 1961. The higher turbidities recorded during September at several stations (Appendix B) were a result of irrigation waste water returns observed at several points in the study area.

Chlorides: Chlorides were low, ranging from 8 to 15 ppm at the various sampling stations.

Sulphates: Sulphates increased at downstream sampling points over a low of 33-44 ppm at Laurel. A considerable contribution of sulphates to the Yellowstone River is affected by the Clark's Fork River as indicated by a maximum concentration of 222 ppm in March, 1962. In this section of river the recommended standard of 250 ppm for drinking water established by the U.S. Public Health Service (1962) is not exceeded.

Nitrates: Nitrates range from an average minimum at Laurel of 0.2 to an average of almost 0.7 ppm at Pompey's Pillar. The high concentration of 2.2 ppm recorded at Pompey's Pillar during September, 1961 (Appendix B) is believed to have been associated with the increased quantity of the irrigation waste water return observed during this sampling period.

Phosphates: Reference is made in the 1955 report by the U.S. Public Health Service, et al, to high natural phosphates (one to three ppm) found to be present in the river during August and September, 1952. The significance of soluble phosphates in natural stream courses lies in the ability of a body of water to produce profuse growths of nuisance algae which contributes to water treatment problems through the fertilizing affects of phosphates in combination with nitrates and other nutrients. Amounts of phosphates too low to be measured were reported during the 1955 survey as determined from water samples taken during November. Up to 1.6 ppm total phosphate and 1.0 ppm ortho-(soluble) phosphate was found at Pompey's Pillar during early November, 1962. (Appendix B). At the same station, the soluble phosphate concentration was immeasurable one month later. This trend is in contrast with other findings concerning the dynamics of soluble phosphate in natural waters. Normally, low phosphate values are prevalent during periods of high biological activity, (APHA, et al, 1960), however, the highest phosphate concentrations here are apparent during late summer and early fall and actually increase between these seasons. The writers of the 1955 report assume the source of the high phosphates as being from underground phosphate bearing strata of the watershed however, if this is true, then the seasonal fluctuation of soluble phosphates should follow the same trend as other chemicals and be highest during the winter. It is suggested that the source of these high phosphate concentrations in the Yellowstone River is from domestic sewage as well as agricultural chemicals applied to the farming land of the watershed and wasted to the river through irrigation return flows. This theory should be investigated further.

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* Reported as $CaCO_3$

The highest average phosphate concentration of 0.9 ppm was apparent at the O'Leary sampling station as compared to 0.26 and 0.3 ppm at Laurel and Billings respectively. This high average was undoubtedly a result of phosphate associated with domestic sewage. Phosphate concentrations were somewhat lower at downstream stations being about 0.6, 0.4 and 0.4 ppm at the Farm House, Huntley and Pompey's Pillar sampling sites, respectively. These quantities of phosphate, though appearing relatively low especially at the upstream stations, are more than ample to produce a fertilizing effect upon the river allowing plankton and algae to reproduce to nuisance proportions.

Total dissolved solids: Filterable residue at 103°C (total dissolved solids) increased at downstream stations over quantities at Laurel with the greatest contribution to the Yellowstone River being from the Clark's Fork River (Appendix B). Concentration of total dissolved solids at Laurel was around 160 ppm and with the 430-500 ppm contribution from the Clark's Fork, levels at downstream stations ranged from 240-360 ppm. The highest concentration was recorded at Huntley.

Loss upon ignition: Another indirect measurement of the amount of organic matter in water is loss of weight by a sample of oven dried (at 103°C.) material upon ignition at 600°C. in a muffle furnace. Organic compounds are reduced to ash by this process and bicarbonates changed to carbonates. The loss in weight after ignition can be considered the total mass of dehydrated organic matter in the sample and a change in HCO_3^- to $CO_3^=$. Again, weight loss of samples upon ignition increases progressively at downstream stations. Average loss at Laurel was about 45 ppm; at Billings, about 60 ppm; at O'Leary's Gravel pit, 75 ppm; and 81-83 ppm at the Farm House, Huntley, and Pompey's Pillar sampling sites.

In conclusion, this section describes some of the chemical and physical characteristics of the Yellowstone River. Organic wastes from the Billings area exert a BOD which results in a minimum dissolved oxygen saturation value of about 70 percent and a minimum dissolved oxygen concentration of 5.5 ppm at the Pompey's Pillar sampling station during late August. The minimum dissolved oxygen saturation value closely approaches the minimum allowable standard of five ppm established by the Montana Water Pollution Council. Obviously, additional organic materials discharged to the river will increase the BOD and exert a greater load on the stream.

Turbidity and nitrates and probably BOD are increased sharply by the return of irrigation waste water.

Also,"natural" phosphate concentrations are thought to be more of a function of irrigated land drainage and domestic sewage discharge than a result of dissolution from underground strata of the watershed.

The relatively high phosphates in combination with other nutrients present provide conditions which may result in abnormally excessive growth of obnoxious taste and odor producing plankton and algae in the Yellowstone River municipal water supplies.

Most Probable Number Coliform Organisms

The isolation of disease-causing organisms from water and waste is not used as a routine test for determining contamination since presently available techniques are tedious and time consuming ("Standards Methods", APHA, et al, 1960). Instead, tests for the presence of coliform bacteria found in the intestines of warm-blooded animals are used as an indication that fecal wastes are present in the water being analyzed.

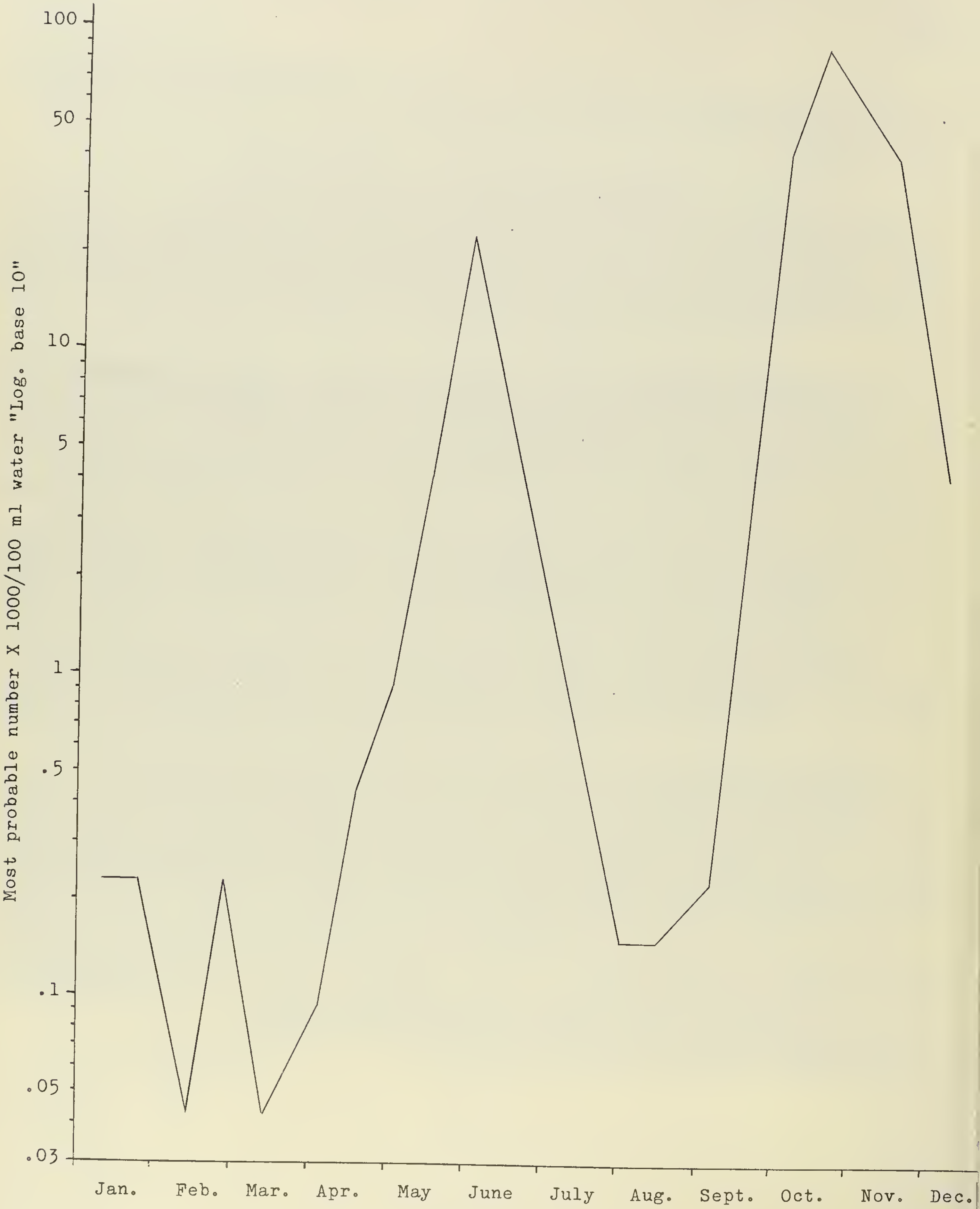
The coliform group of bacteria includes two major groups, *Escherichia coli* and *Aerobacter aerogenes*. The methods of analysis normally used by most bacteriological laboratories make no attempt at differentiation between the two bacteria. "Standard Method" (APHA, et al., 1960) states "such differentiation is of limited value in determing the suitability of water for human consumption, as contamination with either type of coliform organisms renders the water potentially unsatisfactory and of unsafe sanitary quality." In this particular case, however, it would be desirable to differentiate between the two species, since it is almost imperative to determine the effect of beet sugar refinery wastes upon the coliform index of the Yellowstone River. Also, the limits of MPN established by the Montana Water Pollution Council are based on the qualification that the coliforms must be associated with domestic sewage.

Commencing in January, 1960, communities using Yellowstone River water as a source of domestic supply were requested to submit water samples of the raw water to the State Board of Health Microbiology Laboratory in Helena. Among these cities were Laurel, Billings, Forsyth, Miles City and Glendive.

Samples are collected in the standard sterilized bottles used for this purpose and shipped by Railway Express to the State Board of Health Microbiological Laboratory in iced containers. A multi-tube fermentation technique using three tubes and resulting in a most probable number (MPN) of coliform organisms per 100 milliliters of river water was used as the analytical technique (APHA, et al., 1960). Samples were collected at nearly semi-monthly intervals with a total of 71 to 84 being analyzed during the period January 18, 1960 to December 4, 1963 at the various stations (Appendix C).

In general, during any one year at any of the stations, the MPN coliform organisms per 100 milliliter of raw river water sample exhibited two peaks. One peak occurs during the high water season and, after a mid-summer low, another high is encountered with the advent of cold weather. A typical trend in MPN for any one of the stations during any one of the three years is shown by fluctuations at Forsyth during 1961 (Figure 13).

Figure 13. Most probable number of coliform organisms in Yellowstone River water samples from Forsyth, 1961.



Many classical studies have pointed out that each spring, runoff will carry coliform organisms to natural stream drainages from soil and vegetation thus increasing the coliform index of a stream during this period of the year. With low water and the higher temperatures of mid-summer, natural die-off of coliform organisms is increased thus resulting in a mid-summer low and, with the advent of fall rains and cold weather, the coliform index is again increased as a result of land drainage and retardation of coliform die-off.

The major sources of coliform organisms in the study area (Laurel to Glendive) since 1960 include the sewage treatment plant effluents at Laurel and Billings; flume wastes from the Great Western Sugar Company at Billings; meat packing wastes from Billings; flume wastes from the Holly Sugar Company at Hardin; raw sewage from the community of Miles City (until 1962); irrigation water return and land drainage. During 1961, the raw sewage from Miles City was eliminated with the construction of a lagoon.

Yearly averages of MPN coliform organisms for the four years of sampling were computed (Table 11). At Laurel and Billings the yearly average increased from 1960 to 1962 and the increase continued through December 4, 1963 at Billings. A decrease occurred at Laurel during 1963 (Table 11). At Forsyth, the MPN increased from 1960 to 1961, remained about the same during 1962 and increased again during 1963. A ten-fold increase occurred at Miles City between 1960 and 1961 however, the MPN decreased the next year to about one-half the 1961 value and then increased again in 1962. The yearly average at Glendive more than tripled in 1961 over 1960, decreased by nearly one-half in 1962 and remained about the same in 1963. The decrease from 1960 is attributed to the construction and operation of sewage treatment facilities at Miles City. The nearly three-fold increase at Forsyth in 1961 and 1962 over 1961 is discussed below, however, a more gradual increase could be expected with increased loading on sewage treatment plants resulting from expansion of sewer systems, especially at Billings.

Table 11. Yearly average of MPN coliform organisms, 1960-63.

	Average MPN/100 ml			
Station	1960	1961	1962	1963
Laurel	176	588	1206	818
Billings	693	1756	2380	2637
Forsyth	4062	11721	11507	12906
Miles City	661	6939	3567	5652
Glendive	2750	9534	5194	4849

A close examination of the MPN data (Appendix C) reveals a tremendous increase in coliform index during the period September 15, 1961 to April 5, 1962 (Table 12). A higher than normal rainfall occurred during the fall of 1961 followed by a freeze which resulted in considerably more soil adhering to the beets. This, in turn, is believed to have produced the higher MPN values at the sampling stations downstream from Billings. This speculation is at least partially supported by the high quantity of suspended solids recorded in Great Western sugar wastes during the 1961 campaign (Fig. 8; page 24)

Table 12. MPN (Most Probable Numbers) coliform organisms at Forsyth, Miles City and Glendive during the period Sept. 15 to Apr. 15, 1960-63.

Year	Average MPN/100 ml Forsyth	Miles City	Glendive
1960[1]	482	144	450
1960-61	5550	737	3529
1961-62	17565	12683	12989
1962-63	13406	1802	2195
1963[2]	24975	13113	8879

[1] data available for Jan.-Apr. only
[2] data for Sept. 15-Dec. 4

In addition to the general increase from year to year, it is significant to note the increase (or decrease) at downstream stations during any one year (Table 11). During all four years, the MPN increased at Billings over Laurel and at Forsyth over Billings. A decrease occurred between Forsyth and Miles City every year. During 1960, 1961 and 1962 the MPN increased between Miles City and Glendive and decreased slightly in 1963. The decrease at Glendive during 1961-63 is attributed to the installation of the sewage treatment lagoon at Miles City.

As mentioned before, tremendous numbers of coliform organisms are known to be associated with beet sugar refinery flume wastes and for the purpose of analysis, the yearly data are divided between two periods, namely, February through September and October through January. This was done in order to compare the averages during the beet slicing season, October through January (Table 13) and the averages before the beet campaign (Table 14) with the average yearly MPN (Table 11). At Laurel, the MPN during the beet slicing season (Figure 14) was lower during the three years of sampling than the average yearly MPN (Figure 15). Conversely, at the same station, the average before the beet campaigns during each of the three years was higher (Figure 16). At Billings the coliform index during the beet season was higher during all three years. The same is apparent at Forsyth for all three years. At Miles City and Glendive during 1960 and 1961, again the MPN was higher during the beet campaign, however, during 1962 the averages were lower.

Table 13. Average MPN coliform organisms in Yellowstone River water samples, Oct. - Jan., 1960-63.

Station	Average MPN/100 ml 1960-61	1961-62	1962-63
Laurel	28	190	62
Billings	1221	3370	3772
Forsyth	7971	21277	22875
Miles City	1060	15360	1849
Glendive	4190	15917	2842

Figure 14. Average MPN coliform organisms in Yellowstone River water samples collected during the period, Oct.-Jan., 1960-63

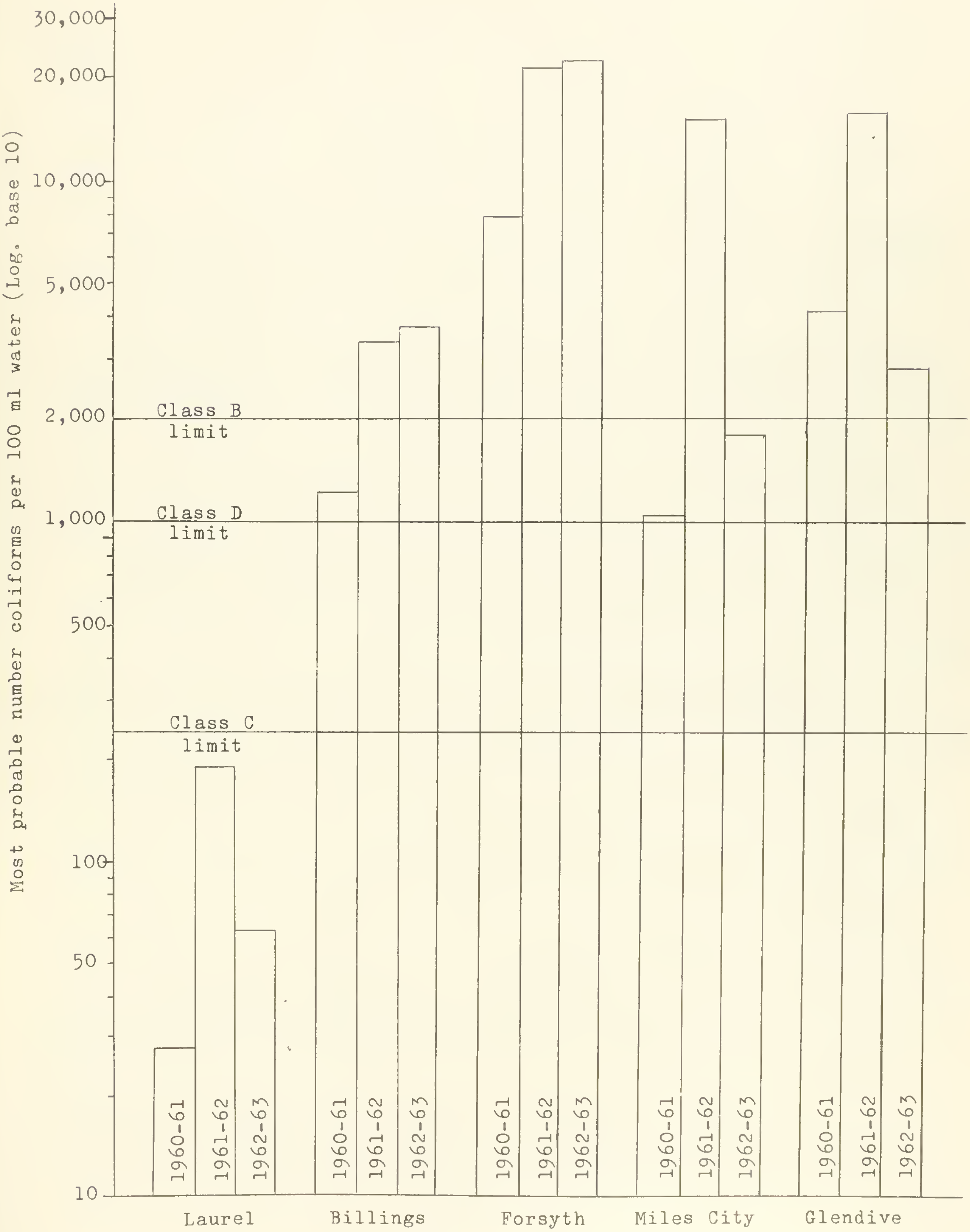


Figure 15. Average yearly MPN coliform organisms in Yellowstone River water samples, 1960-62.

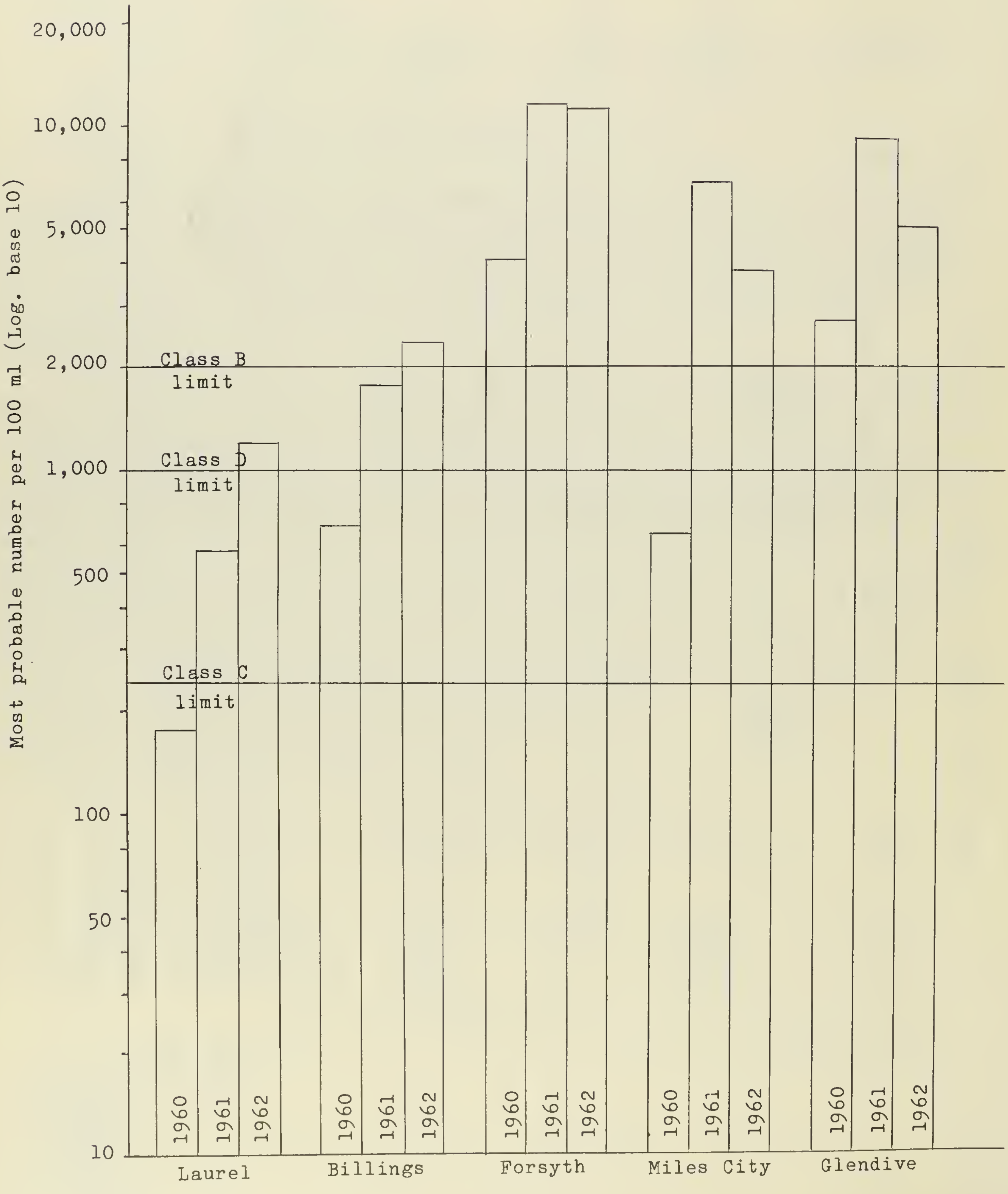


Figure 16. Average MPN coliform organisms in Yellowstone River water samples during the period, Feb.-Sept., 1960-62.

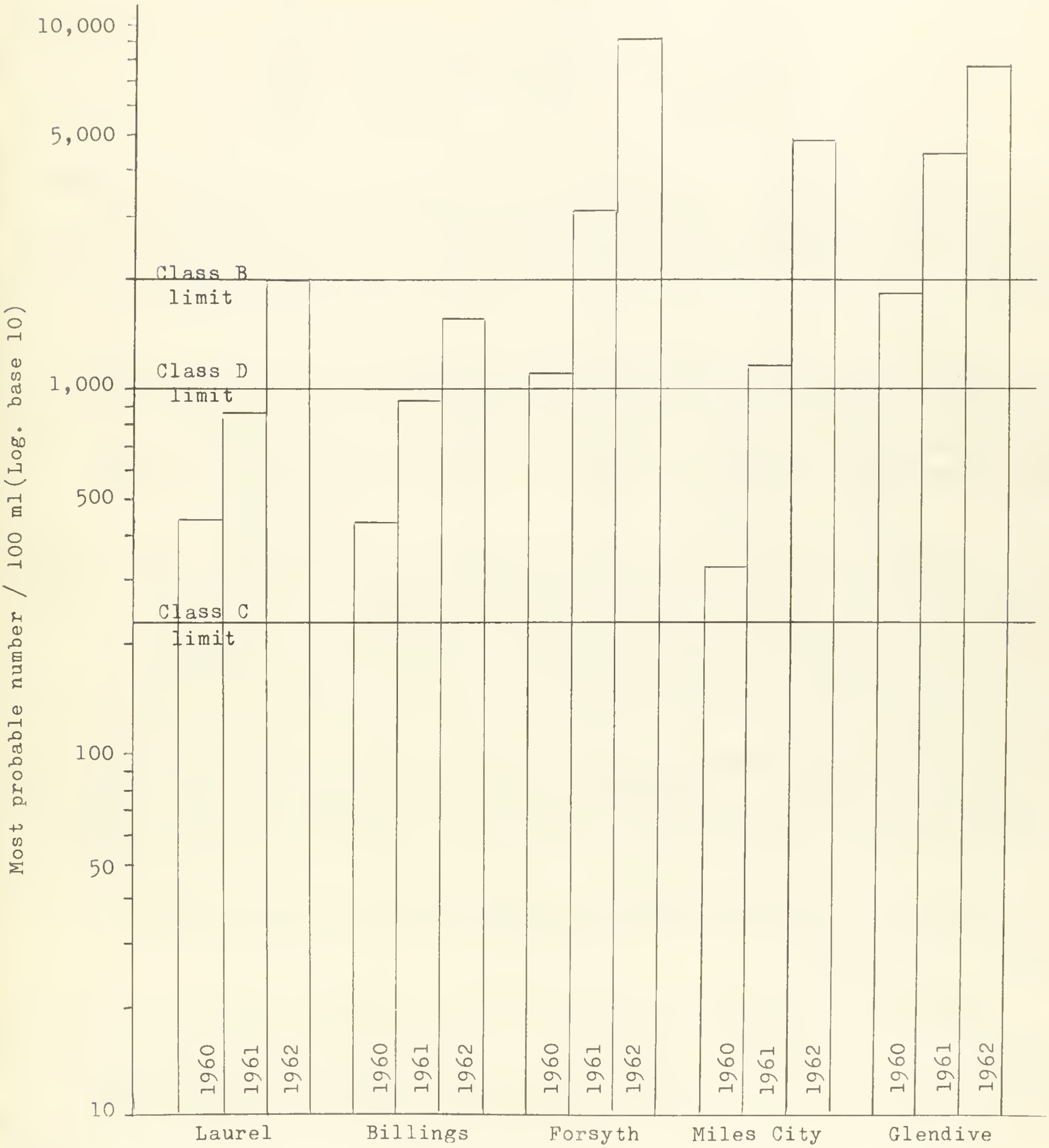


Table 14. Average MPN coliform organisms in Yellowstone River water samples, Feb. - Sept., 1960-62.

Station	Average MPN/100 ml 1960	1961	1962
Laurel	440	860	1995
Billings	443	939	1585
Forsyth	1112	3128	9216
Miles City	328	1170	4919
Glendive	1852	4052	7800

Although the late fall-early winter coliform index is considerably higher than the yearly average or the average for the other seasons of the year, it appears that the general increase from year to year at all stations and the contamination from treated and untreated sources have as much influence on the yearly average as does the contribution of coliform organisms by beet sugar wastes.

The Yellowstone River below Livingston is classified as a Class B stream and should be acceptable for drinking after treatment, swimming, fishing, recreation and industrial and agriculture usage. The maximum permissible limits of the most probable number of coliform organisms per 100 milliliters of water (when associated with domestic sewage) for each use is listed in Table 15. For a Class B water supply, its usage for swimming would limit the maximum coliform bacteria to 240 per 100 ml.

A comparison of the yearly average MPN with the maximum permissible limits (MPL) readily indicates that the Yellowstone River from Laurel to a point below Glendive should be restricted from swimming and bathing purposes at the present time. Only during 1960 was the MPN lower than the MPL Further, on the basis of the 1962 average, considerable reduction in sources of contamination is indicated at all stations in order that the stream will meet the MPL for recreational purposes, other than swimming and bathing (fishing only). It is logical that the yearly average of MPN is a poor basis for comparison with the maximum permissible limits for a swimming stream since swimming is restricted to the warmer months. However, it is pointed out that the MPN during the periods from mid-July to mid-September, 1962 and 1963 still averages considerably higher than the MPL for a swimming stream at all stations (Table 16). Again no differentiation was made between coliform bacteria associated with domestic sewage and the other coliform bacteria also measured by the MPN coliform test.

Further, since 1962, the MPN at Billings, Forsyth, Miles City and Glendive has averaged above the maximum permissible limits established for a Class B water supply.

The need of chlorination of primary sewage effluents is apparent. Chlorination of mechanical sewage treatment plant effluents at Livingston, Laurel and Billings is to be started on July 1, 1964. Adequate chlorination will essentially eliminate all coliform bacteria from these sewage effluents. Sewage lagoon effluents are very low in coliform bacteria particularly during the summer months.

Table 15. Maximum permissible limits of MPN coliform organisms for the various water uses.

Class	Type of Use	MPL of MPN per 100 ml
B	Water supply requiring complete treatment	2000
C	Recreation (swimming, bathing)	240
D	Recreation (fishing only)	1000

Table 16. Average MPN coliform organisms during the period mid-July to mid-September, 1960-63.

	Average MPN/100 ml			
Station	1960	1961	1962	1963
Laurel	162	201	1610	2396
Billings	189	2559	987	3115
Forsyth	355	177	18200	3410
Miles City	115	276	2967	1698
Glendive	2688	8743	16017	530

Discussion of USGS Phenol Samples

During the period September 30, 1953 to December 6, 1962, 94 samples from the Laurel and Billings stations and 93 samples from Huntley (Appendix A) were analyzed.

The average concentration of phenolic compounds recorded at the BL&I Canal above Laurel during the entire sampling period was 4.2 ppb. (Table 17). Levels ranged from 0 to 30 ppb with the highest quantities occuring October, 1953 to June, 1954 (Appendix A). The highest reading since that time was 19.8 ppb during February, 1962.

The average phenol level at Billings was 5.7 ppb (Table 17) and ranged from 0 to 150 ppb (Appendix A). As with Laurel, the period of highest concentrations was October 1953 to June 1954.

The level at Huntley averaged 10 ppb and ranged from 0 to 90 ppb, and again the highest readings occurred during the winter of 1953-54 (Appendix A).

These average concentrations of phenolic compounds are compared statistically later in this section; however, examination of the data indicates that some grouping of information is in order. Several pertinent facts and indications other than the year-to-year trend are apparent. Among these entities was an apparent trend toward higher phenols at downstream stations during cold weather.

Table 17. Average concentrations of phenolic compounds and differences in "phenols" among stations of Yellowstone River water samples since January, 1953 and January, 1958.

	Phenols (ppb)			Difference (ppb)		
	Above Laurel	Above Billings	Huntley	Billings-Laurel	Huntley-Billings	Huntley-Laurel
Average since 1953	4.2	5.7	10.0	1.5	4.3	5.8
Average since 1958	3.7	4.3	8.7	0.6	4.6	5.1

Phenol levels in relation to water temperature: Since the chlorophenolic odors in municipal water supplies downstream have occurred, for the most part, during the late fall and early winter, it is reasonable to assume that cold water temperatures may play an important role in the problem.

The degradation of phenolic compounds is undoubtedly accomplished principally by the microbiological element of the aquatic community. The metabolic rate of these flora and fauna decreases directly with decreases in the temperature of the environment. Thus, it is logical to expect more phenolic compounds at a given location in the river during cold weather than during the summer, since phenolic compounds originating at a given point can be expected to persist at points further downstream during periods of cold-water temperature.

In order to examine this postulate, quantities of phenolic compounds at the various stations were tested as a function of water temperatures (Appendix A). River water temperatures are those recorded at the Billings water treatment plant. The design of this test is based on the theory that phenols originating above an upstream station would persist at a downstream station during cold weather and thereby be superimposed upon the phenol level already existent at the downstream station. This would result in higher levels during the winter. For example, a given concentration of phenols at Billings could be expected. If degradation is retarded by cold-water temperatures, practically the same level could be expected at Huntley in addition to those phenols which originate from natural or artificial sources between Billings and Huntley. The same supposition can be advanced concerning the Billings and Laurel relationship. Theoretically, winter-time phenol concentrations at Billings (1) and Huntley (2) would be:

(1) Phenols in river at Laurel + phenols added between Laurel and Billings= phenols at Billings
(2) Phenols in river at Billings + phenols added between Billings and Huntley= phenols at Huntley

and summer levels would essentially be:

(1) Phenols at Billings only

(2) Phenols at Huntley only

Using this method of "standardization" and employing the design: phenols at Huntley minus phenols at Billings versus water temperature (Figure 17), it is quite apparent that the level is dependent upon water temperature. However, in order to determine the validity of this, the null hypothesis that the regression coefficient is equal to zero was tested, using Student's "t" distribution (Ostle 1954), and found to differ significantly.

Therefore, the data suggest an indirect and strong correlation between phenol concentration and water temperature. That is, as the temperature decreases, the level of phenolic compounds at Huntley increases.

A note of explanation concerning statistical analysis is in order here. With regards to the analysis of results from any group of continuous variables, one is not only interested in the mean (average) of a set of measurements but also the range of variation of observations from the mean. In addition, one is interested in determining how much confidence can be placed in the average value obtained from a group of measurements.

By use of analysis of variance based on mathematical models, statisticians have evolved a system of determining the extent of confidence which can be placed upon a statistic such as the mean. This results in conclusions such as a given mean value will be obtained by repeated sampling from a specific population of variables a certain percentage of the time providing that methods of sampling are kept constant and that the variables are distributed around the mean in a normal or known fashion.

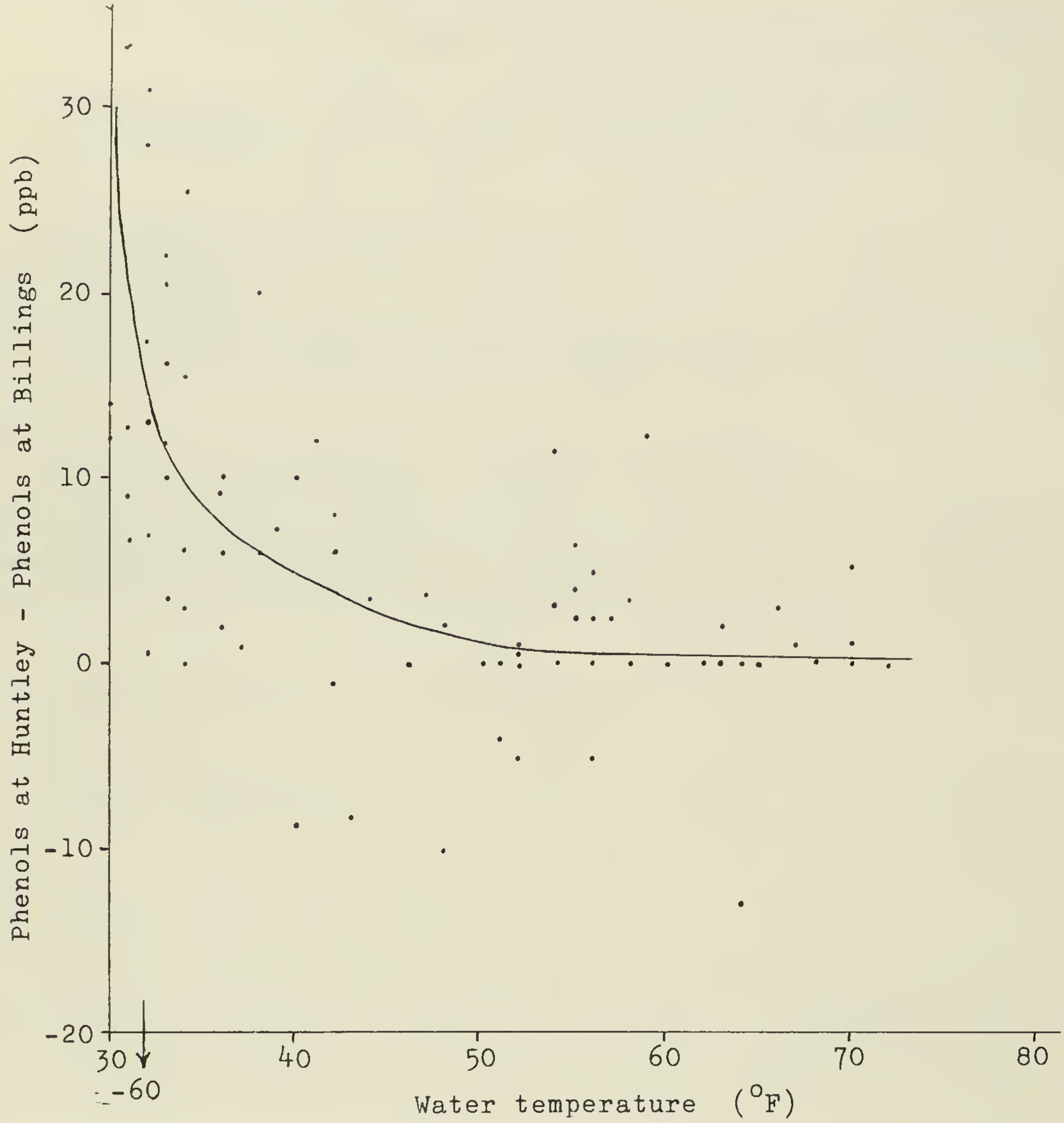
When a statement is made that two averages differ significantly from one another at a confidence level of 90 percent (or with a 10 percent chance for error), this can be interpreted as meaning that out of 100 additional averages computed from samples taken from each of the two populations of variables, 90 averages would differ from each other and the other 10 would be essentially the same. This occurs simply by chance alone.

Two major entities function to affect the degree of confidence which can be placed upon a statistic, viz.; (1) the extent of variation of individual measurements from the average of all the variables, and (2) the sample size. Obviously, if the variation is great, little confidence can be placed in the assumption that the mean truly represents the population of measurements as a whole. When variation is great, confidence can be restored by taking more measurements. As the sample size increases, the variation decreases, thus, more confidence can be placed in a given mean value.

In this report, all statistical analyses were conducted at a confidence level of 90 percent except where noted otherwise.

The testing of hypotheses such as the one immediately above, is also based upon variation. The testing of null hypotheses, i.e., testing the obverse theory rather than the obvious theory, is accepted by statisticians as standard procedure since it is apparently more significant to reject that which is not true than accept that which is true.

Figure 17. Difference between phenolic compounds at Huntley and Billings as a function of water temperature, 1953-62.



Concerning the comparison of differences in phenol levels between Huntley and Laurel versus water temperature (Figure 18), again, a strong indirect correlation exists as suggested by rejection of the hypothesis that the slope of line is equal to zero.

A "least squares fit" to differences between phenols at Billings and Laurel as a function of water temperature (Figure 19) indicates that a negative correlation exists; however, the slope of line does not prove to be different than zero. This appears to contradict the above results. The most probable factor having a bearing may possibly be found in phenol levels, per se. The average level at Laurel during the entire sampling period was 4.2 ppb (Appendix A). The level at Billings was 5.7 ppb. The Student "t" test (Dixon and Massey, 1957) indicates that the difference of 1.5 ppb is not significant. Levels since 1958 (Table 17) were even lower and the average difference was considerably smaller. Although the metabolism of the aquatic community is greatly retarded during cold weather, some activity proceeds. It is speculated that the bacterial flora were able to degrade the lower levels of phenolic compounds in the river above Billings, thus resulting in no great difference in levels between the two stations.

With regards to interpretation of these results, it must be considered, in addition to colder temperatures allowing phenolic compounds to persist in the river, that more phenols are discharged to the river during the winter than during the warmer seasons.

If the postulation that phenolic compounds persist longer in the river during cold weather is true, then it appears that the critical temperature is around 40°F. That is, higher levels of phenols can be expected when the water temperature decreases below 40°F. In addition, it appears that a critical, minimum level is involved since the lower levels of phenols at Billings and Laurel did not show a correlation with water temperature. If the speculation regarding this comparison has basis in fact, winter-time, phenol levels up to about 5 ppb can be degraded in the river while levels greater than 5 ppb can be expected to persist in the aquatic environment.

Comparison of levels of phenolic compounds:

Since levels of phenolic compounds in the river water samples varied considerably from season to season, the data were grouped according to seasonal averages.

As mentioned before, winter averages at all stations were much higher. For the entire sampling period, the overall winter average at Laurel since 1953 was 7.6 ppb. At Billings, the average was 13.9 ppb and at Huntley, 23.0 ppb (Table 18).

Using Student's "t" test, the hypothesis that the averages were equal at Laurel and Huntley must be rejected, even at the 95 percent confidence level. Therefore, the average winter level of phenols at Huntley were significantly higher than those at Laurel. Though not nearly as significant (60 percent confidence level), the average phenol concentration at Huntley proves higher

Figurel8. Difference between phenolic compounds at Huntley and Laurel as a function of water temperature, 1953-62.

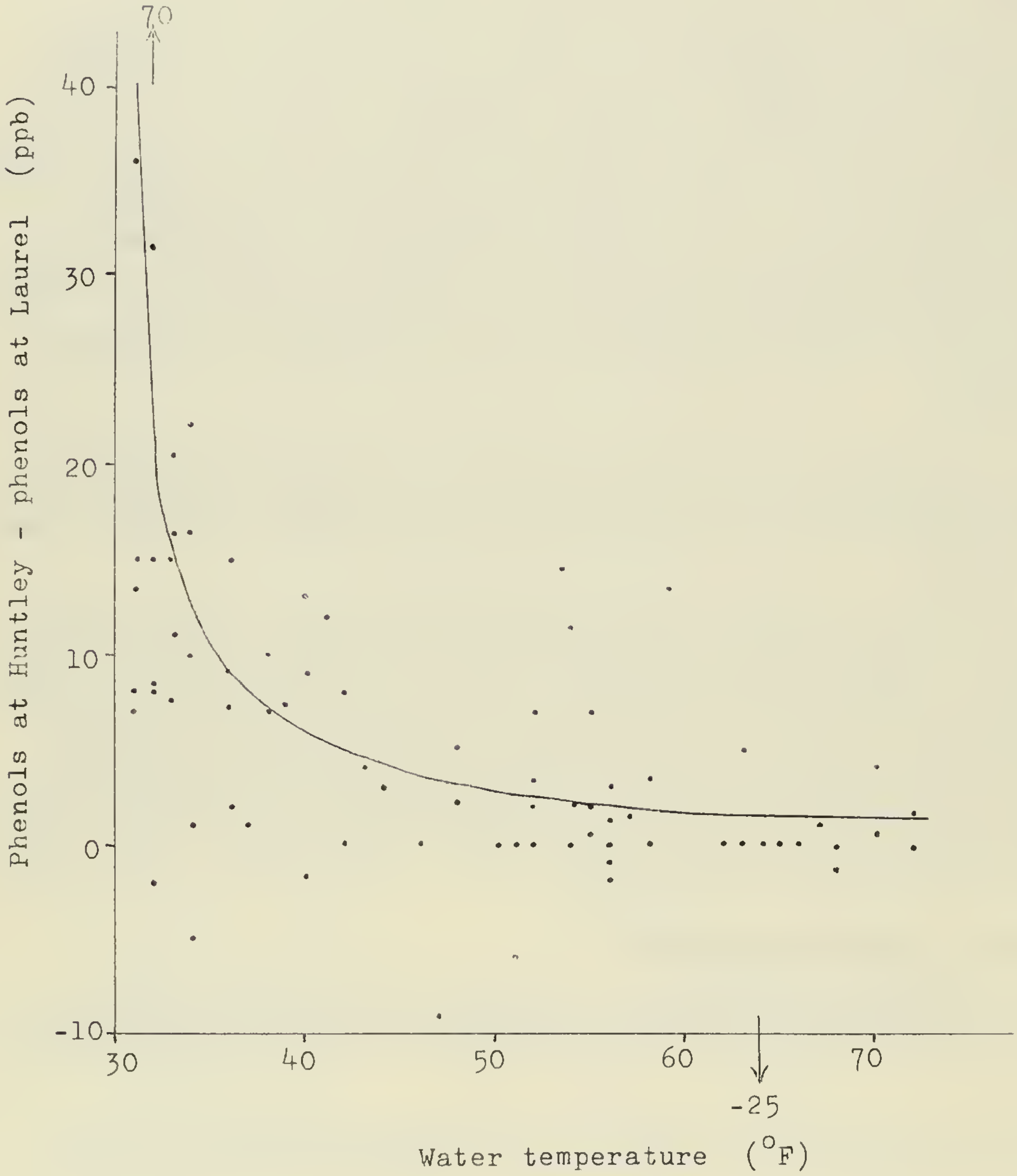


Figure 19. Difference between phenolic compounds at Billings and Laurel as a function of water temperature, 1953-62.

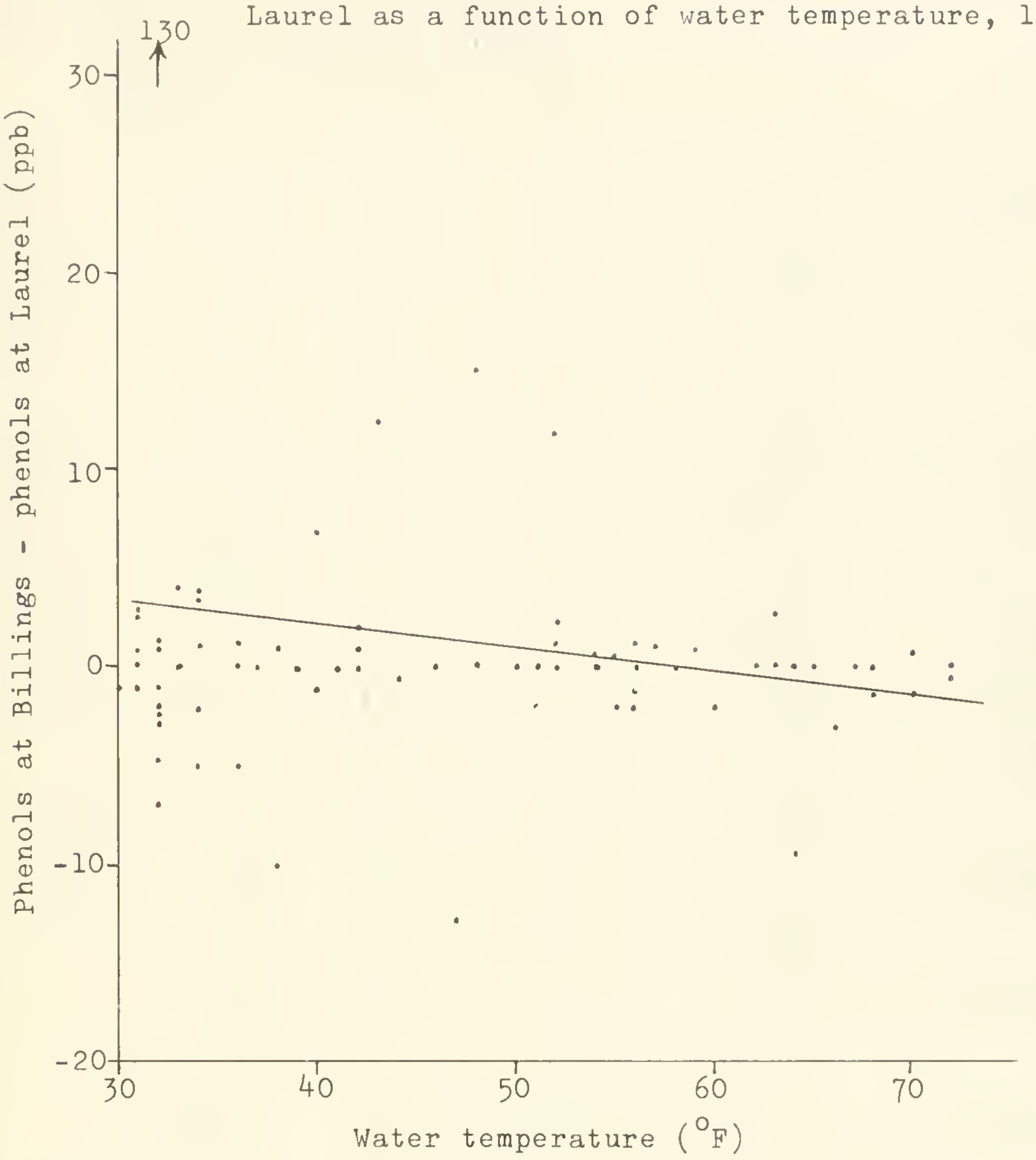


Table 18. Seasonal averages of concentrations of phenolic compounds in Yellowstone River water samples, 1953-62.

Year	Season	Phenolic Compounds (ppb) Laurel	Billings	Huntley
1953	Fall	5.0	12.0	8.3
1953-54	Winter	25.0	85.0	65.0
1954	Spring	7.5	10.0	15.0
	Summer	15.7	10.3	2.5
	Fall	--	--	--
1954-55	Winter	4.5	0.5	18.0
1955	Spring	2.1	0.5	6.8
	Summer	0.2	0.5	3.0
	Fall	1.5	1.7	9.1
1955-56	Winter	1.5	2.2	20.5
1956	Spring	0.7	0.5	5.8
	Summer	1.4	0.7	2.0
	Fall	1.4	1.3	8.0
1956-57	Winter	5.0	4.2	15.3
1957	Spring	3.0	2.0	3.3
	Summer	5.4	6.7	7.7
	Fall	2.5	2.8	9.0
1957-58	Winter	1.2	0.3	0.8
1958	Spring	11.1	7.2	7.4
	Summer	0.4	0.4	0.3
	Fall	1.9	5.5	3.8
1958-59	Winter	1.7	3.2	11.8
1959	Spring	0	0	0
	Summer	2.1	1.4	3.0
	Fall	1.8	3.6	11.1
1959-60	Winter	6.6	5.8	23.6
1960	Spring	0.8	1.2	5.3
	Summer	0	0	0
	Fall	7.8	6.6	18.9
1960-61	Winter	6.9	8.7	14.0
1961	Spring	2.8	2.7	6.3
	Summer	2.2	2.9	5.7
	Fall	4.5	3.9	8.4
1961-62	Winter	15.9	15.0	38.2
1962	Spring	6.2	18.4	11.8
	Summer	0	0	0
	Fall	2.0	2.0	3.5
Averages since 1953	Winter	7.6	13.9	23.0
	Spring	3.8	4.7	6.8
	Summer	3.0	2.5	2.7
	Fall	3.2	4.4	8.9
Averages before January 1958	Winter	9.0	23.0	29.7
	Spring	3.3	3.2	7.7
	Summer	5.7	4.6	3.8
	Fall	2.6	4.4	8.6
Averages since January 1958	Winter	4.6	6.6	17.7
	Spring	4.2	5.9	6.2
	Summer	0.9	0.9	1.8
	Fall	3.6	4.3	9.1

than that at Billings. No difference is apparent in levels at Laurel and Billings based on the average phenol concentration at the two stations during the entire period of sampling, 1953-62.

A closer examination of the winter averages for each year indicates a definite change in phenol levels before and after the winter of 1957-58. Averages prior to January, 1958 deomonstrate a decrease from 9.0 to 4.6 ppb since that time at Laurel, and from 29.7 to 17.7 ppb at Huntley (Table 18). The greatest change was recorded at the Billings station where the level prior to 1958 decreased from 23.0 ppb to 6.6 ppb since 1958. The decrease in average phenol content at Billings can be proven significant at a 60 percent confidence level.

Considering a comparison of the winter averages before and after 1958 among the three stations (Table 18), the difference between the Laurel and Billings levels and the difference between the Billings and Huntley averages prior to 1958 does not prove significant, i.e., levels at Billings were not significantly higher than levels at Laurel and levels at Huntley were not higher than levels at Billings. However, at the 80 percent confidence level, the average phenol content of Huntley samples before 1958 proves higher than that at Laurel. Since 1958, at the same chance for error, the phenol level at Huntley was higher than the levels at both Billings and Laurel while the average at Billings proves not to be different than that at Laurel.

With the significant decrease in phenols at Billings during the period 1958-1962 and the difference in level between Huntley and Billings proving significantly higher since 1958 (29.7-23.0 = 6.7 ppb before 1958 and 17.7-6.6 = 11.1 ppb since 1958 (Table 18), it appears that a definite reduction in the quantity of phenolic compounds discharged to the river between Laurel and Billings occurred during the winter of 1957-58. This reduction is attributed to the pollution abatement program carried out by the Farmer's Union Central Exchange oil refinery at Laurel.

The average phenol level since 1953 during the spring and fall seasons at Billings and Huntley were intermediate between winter and summer averages (Table 18).

Average level during the spring at Billings was 4.7 ppb and at Huntley, the average was 6.8 ppb. At Laurel, the average concentrations of phenolic compounds in the spring, fall and summer samples since 1953 were about the same, viz., 3.8, 3.0 and 3.2 ppb, respectively.

A statistical comparison of spring levels among the various stations indicates that the average concentration of phenolic compounds in river water samples was significantly higher at Huntley than at Laurel since initiation of the sampling program. No difference was apparent among levels at Laurel and Billings as well as Billings and Huntley, however.

Little change occurred in the average spring-time levels of phenolic compounds in the river water samples at a specific station after 1958 as compared to levels before 1958. The average at Laurel increased from 3.3 to 4.2 ppb, and the level at Billings increased from 3.2 to 5.9 ppb. The phenol content of water samples from Huntley decreased from 7.7 to 6.2 ppb. None of the changes in levels prove significant at any reasonable confidence level.

Prior to 1958, no difference is indicated by Student's "t" test between Laurel and Billings while at the 70 percent confidence level (30 percent chance for error), phenols at Huntley were higher than those at Billings. Also, at the 80 percent level, the Huntley average during the spring proves to be higher than the Laurel average. Since 1958, no significant difference was apparent among average, spring-time, phenol levels at the three stations.

The summer-time levels of phenolic compounds for the entire sampling period in river water samples were the lowest of the seasonal averages at all stations and were close to the same. At Laurel and Billings the summer averages were 3.0 and 2.5 ppb respectively (Table 18). The average at Huntley during this season of the year was 2.7 ppb. Statistically, the average spring-time level of phenols at any given station did not prove significantly different than the average at any other station during the period of time since the start of sampling in 1953.

Considerable change in the average summer-time level of phenol compounds occurred since 1958 as compared to the average prior to 1958 (Table 18). The average at Laurel decreased from 5.7 ppb prior to 1958 to 0.9 ppb after that year. This proves to be different at the 83 percent confidence level. At Billings, the average was 4.6 ppb before 1958 and 0.9 ppb since that date. At the 85 percent confidence level, the difference is significant. The reduction in spring-time averages from 3.8 to 1.8 ppb at Huntley during the same periods of time does not prove significant until a 32 percent chance for error is acceptable (68 percent confidence level).

Fall averages of phenolic compounds during the entire sampling period were 3.2 ppb at Laurel, 4.4 ppb at Billings, and 8.9 ppb at Huntley (Table 18). Since water temperatures are cooler during this season of the year, phenol content of river water samples can be expected to be higher than summer levels. Statistically, the level at Huntley proves to be higher than the Billings average at a 95 percent confidence level. A highly significant difference (99 percent confidence level) is apparent between the Huntley and Laurel levels; however, the difference between the Billings and Laurel level does not become significant until a 35 percent chance for error is accepted.

Little change is apparent between average fall phenol levels prior to and after 1958 (Table 18 . Fall averages prior to 1958 were 2.6 ppb at Laurel, 4.4 ppb at Billings and 8.6 ppb at Huntley. Since 1958, the respective averages were 3.6, 4.3 and 9.1 ppb. At no station did averages before 1958 prove to be different than levels after 1958 by Student's "t" test. Among stations, however, prior to 1958, the difference in average phenols during the fall at Huntley and Laurel was highly significant (one percent chance for error). Also, the null hypothesis that phenols at Billings were equal to those at Huntley must be rejected at a confidence level of 86 percent. The phenol level at Billings during this period of time does prove different than the level at Laurel. Since 1958, practically the same results are obtained by analyses in that no difference is apparent between Laurel and Billings averages while the Huntley phenol level is significantly higher than the Billings and Laurel levels (Huntley vs. Billings and Huntley vs. Laurel at 84 and 88 percent confidence levels, respectively).

In discussion of this section on average seasonal levels of phenolic compounds in Yellowstone River water samples collected from sites near Laurel, Billings and Huntley, the effect of river flow rates cannot be disregarded. If the same quantity of waste is discharged to the river at all times, a higher concentration will be recorded in the river during low flow periods and lower concentrations during high flow periods. Although a complete record of river flows during the sampling period is not included here, in general, two periods of low river flow occur in the Yellowstone River, viz., late summer and mid-winter. If late summer and mid-winter minimum flow rates are about the same, e.g., 3000 cfs, the concentration of phenols at Huntley during the winter (23 ppb) and during the summer (2.7 ppb) would represent about 300 and 35 pounds per day total phenol respectively. With low concentrations of phenols occurring during the summer and high concentrations during the winter, it appears that water temperature plays more of a role in determing levels of phenolic compounds than does rate of river flow.

If, as the data suggest, the level of phenols at which persistence of these compounds in the river can be expected is greater than 5 ppb, then, since 1958, winter and spring averages at Billings and Huntley exceed this critical level being 6.6 ppb at Billings and 17.7 at Huntley. The average at Huntley during the spring and fall also exceeds this amount (Table 18).

A general reduction in the quantity of phenols in the river occurred after January, 1958, especially during the winter. This decrease is coincident with the installation and operation of treatment facilities at the Farmer's Union Central Exchange oil refinery at Laurel.

Trends in levels of phenolic compounds:

Besides a comparison of seasonal averages of phenolic compounds, an analysis of the trend in levels of phenols must be considered.

For the purpose of comparison, seasonal averages of phenolic compounds were plotted against years and, though the result may not have described a straight line, "least squares fits" were computed from the equation:

$Y = a + b\,x$

where Y = phenol concentration in ppb
a = Y intercept
b = slope of line
and X = year

Years were assigned a numerical value commencing with one for 1953 or 1954 and ending with 9 or 10 for 1962. For each season, least squares fits were computed for the entire sampling period (since 1953) and for the period before and since 1958. In order to determine the validity of apparent slope of line, the null hypothesis that "b" is equal to zero was tested. If the hypothesis is rejected, then it can be stated that a definite change is apparent in phenol average from one year to the next as proven at the stated confidence level.

During the winter season, for the entire sampling period since 1953, the trend of phenol levels at all stations has been downward (Figure 20). This trend is most pronounced at Billings and least evident at Laurel. The null hypothesis that the slopes of line are equal to zero must be accepted for both Laurel and Huntley; thus, little change has occurred in phenol concentrations at these two sites since 1953. However, the slope of line of the Billings seasonal averages is different from zero at a confidence level of 72 percent. The reduction in the discharge of phenolic compounds to the river above Billings as suggested by comparison of averages prior to and since 1958, also lends significance to this downward trend.

Prior to 1958, the trend in winter averages (Figure 2, page 11) was steeply downward at all stations. All regression coefficients (slopes of line) prove to be different than zero at confidence levels varying from 68 to 78 percent. The strongest correlation exists at Huntley. Since 1958, all regression coefficients prove to be different from zero at a chance for error of less than 6 percent. Thus, the apparent upward trend in phenol levels at all stations during the winter since 1958 is significant.

Since the start of sampling in 1953, average "phenols " during the spring (Figure 21) have shown a slight downward trend at Laurel and Huntley when the data are fitted to a straight line equation. At Billings, an upward trend is indicated which proves significant at a chance for error of 30 percent.

At all stations during the period 1954 through 1957, the average spring level of phenols has regressed sharply (Figure 22). The line slopes prove significant at confidence levels varying from 69 at Laurel to 92 at Huntley (Billings, 70 percent). Again, a significant decrease in the quantity of phenolic compounds discharged to the river prior to 1958 is indicated. Since 1958, the trend has been upward (Figure 22) at Billings and Huntley, however, the regression coefficient does not prove significant at any reasonable confidence level. At Laurel, the downward trend has continued but, again, the data describe nearly a level slope of line.

In conclusion, little change in the average phenol level during the spring at the three sampling stations is indicated since 1958.

Figure 20. Concentration of phenolic compounds in Yellowstone River water samples during the winter, 1953-62.

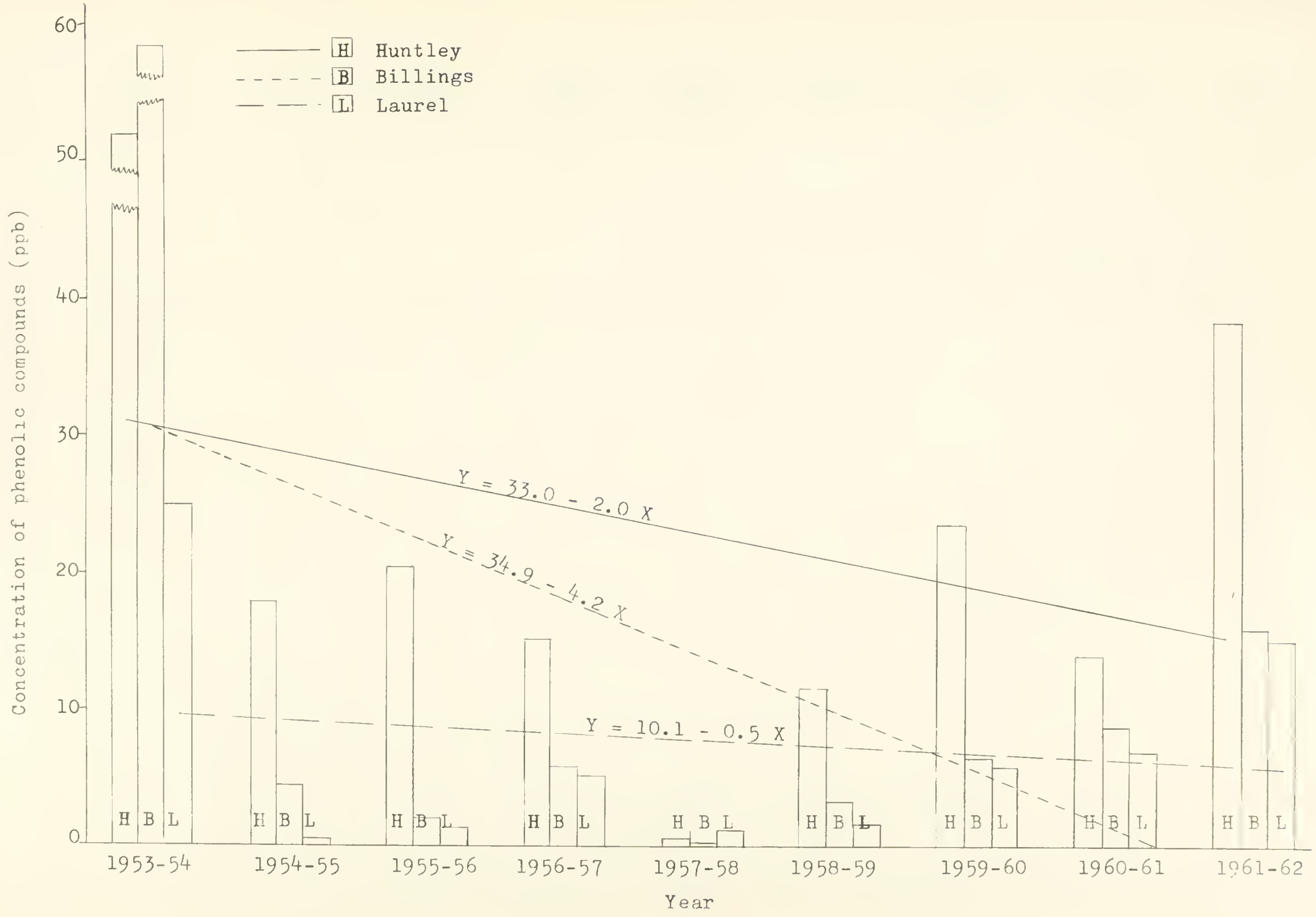


Figure 21. Concentration of phenolic compounds in Yellowstone River water samples during the spring, 1953-62.

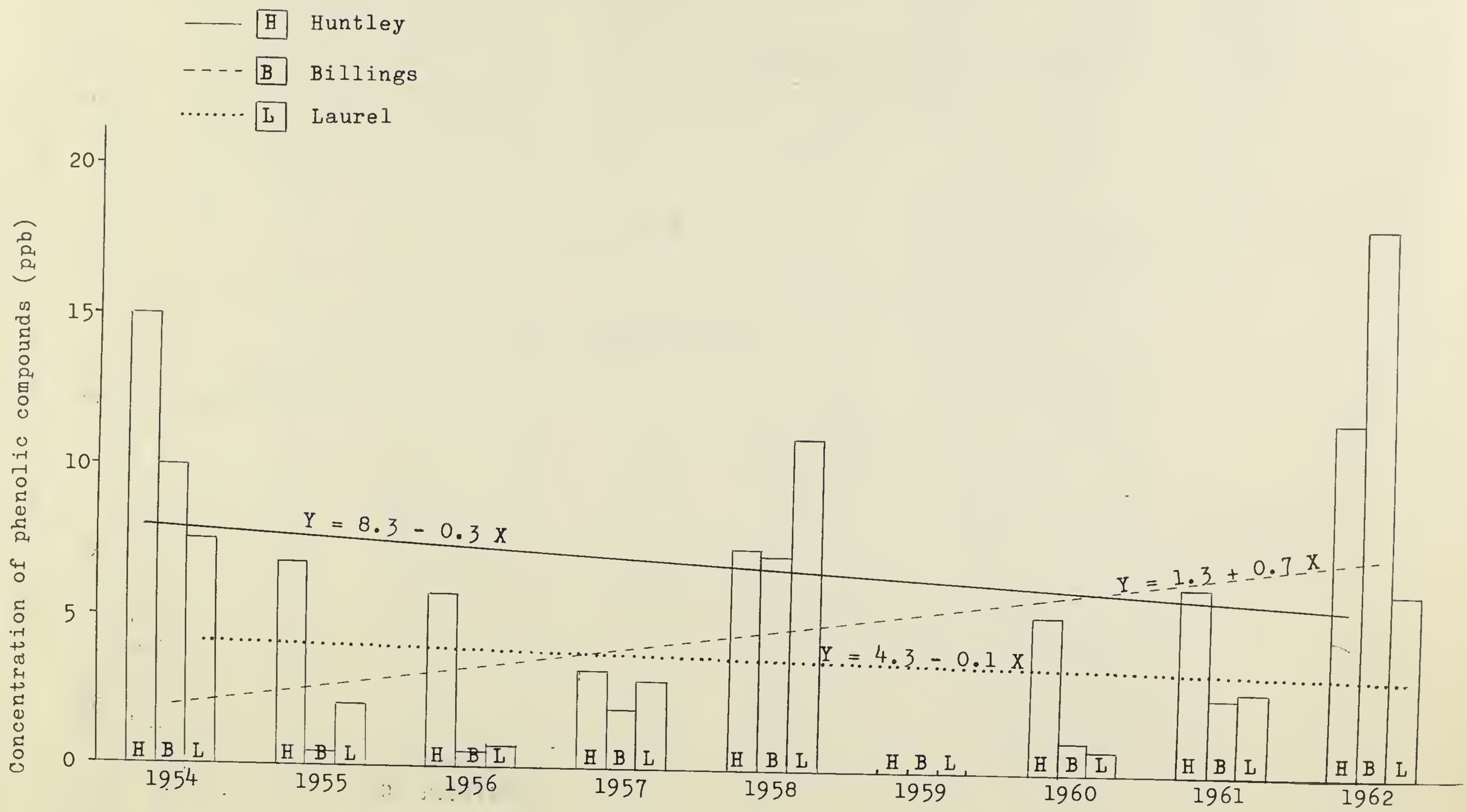
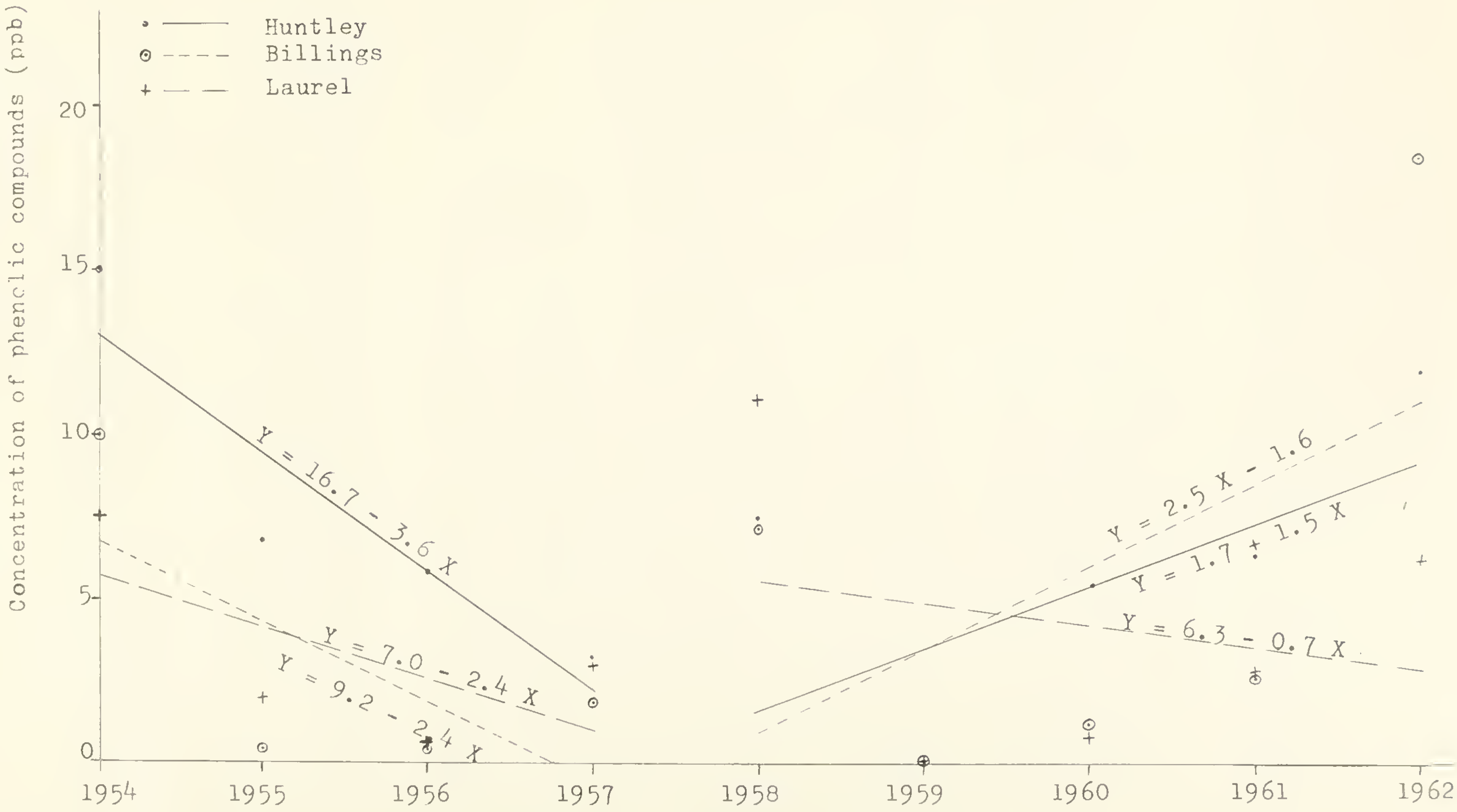


Figure 22. Concentration of phenolic compounds in Yellowstone River water samples prior to and since 1958 during the spring, 1954-62.



Average phenol levels during the summer are considerably lower than those during the other seasons of the year, but some change in levels since 1954 is indicated (Figure 23). The downward trends at Laurel and Billings prove significant at a 12 and 7 percent chance for error. At Huntley, the slope of line since 1954 does not prove to be different from zero at any reasonable confidence level. Thus, during the summer since the start of sampling, the concentration of phenolic compounds at Laurel and Billings has decreased significantly while the seasonal average at Huntley has remained relatively constant.

Prior to 1958, during the summer the downward trend at Laurel and the upward trend at Huntley (Figure 24) prove to be significant at confidence levels of 63 and 71 percent respectively. The apparent downward slope of line described by the summer-time phenol averages at Billings does not prove to be statistically different from a level line. Since 1958, none of the regressio coefficients prove to be different from zero suggesting little or no change in the concentration of phenolic compounds at any of the sampling stations.

During the fall season since the start of sampling in 1953, average phenol levels of water samples from Laurel and Huntley have remained about the same (Figure 25). At Billings, a decrease is indicated with the slope of line proving different from zero at a confidence level of 65 percent.

Prior to 1958, the average concentration of phenolic compounds at Laurel and Billings during the fall has decreased. The regression coefficients (Figure 26) prove to be different from zero with a 30 and 22 percent chance for error, respectively. As a result of considerably less variation, the upward trend at Huntley during the same period proves significant at a confidence level of 92 percent. Since 1958, the levels at Laurel and Huntley have remained about the same while the average at Billings has decreased. The latter proves significant at a 73 percent level of confidence.

Seasonal averages of phenols versus stream criteria:

The maximum permissible limit (MPL) for phenolic compounds eatablished by the Montana Water Pollution Control Council for a Class B water supply is five ppb. This section of the Yellowstone River is classified as a Class B stream.

Since 1958, the seasonal average of phenolic compounds at Billings and Huntley during the winter and spring have exceeded the MPL. The averages at Billings during the two seasons have been 6.6 and 5.9 ppb (Table 18) while at Huntley, the levels have been 17.7 and 6.2 during the winter and spring respectively. In addition, the fall average at Huntley since 1958 has been 9.1 ppb.

If the level of phenolic compounds at which persistence in the river can be anticipated is five ppb, the fall and winter averages of 9.1 and 17.7 ppb at Huntley since 1958 could be expected to result in obnoxious odor in drinking water at some point downstream from Huntley.

Figure 21. Concentration of phenolic compounds in Yellowstone River water samples during the summer 1954-62.

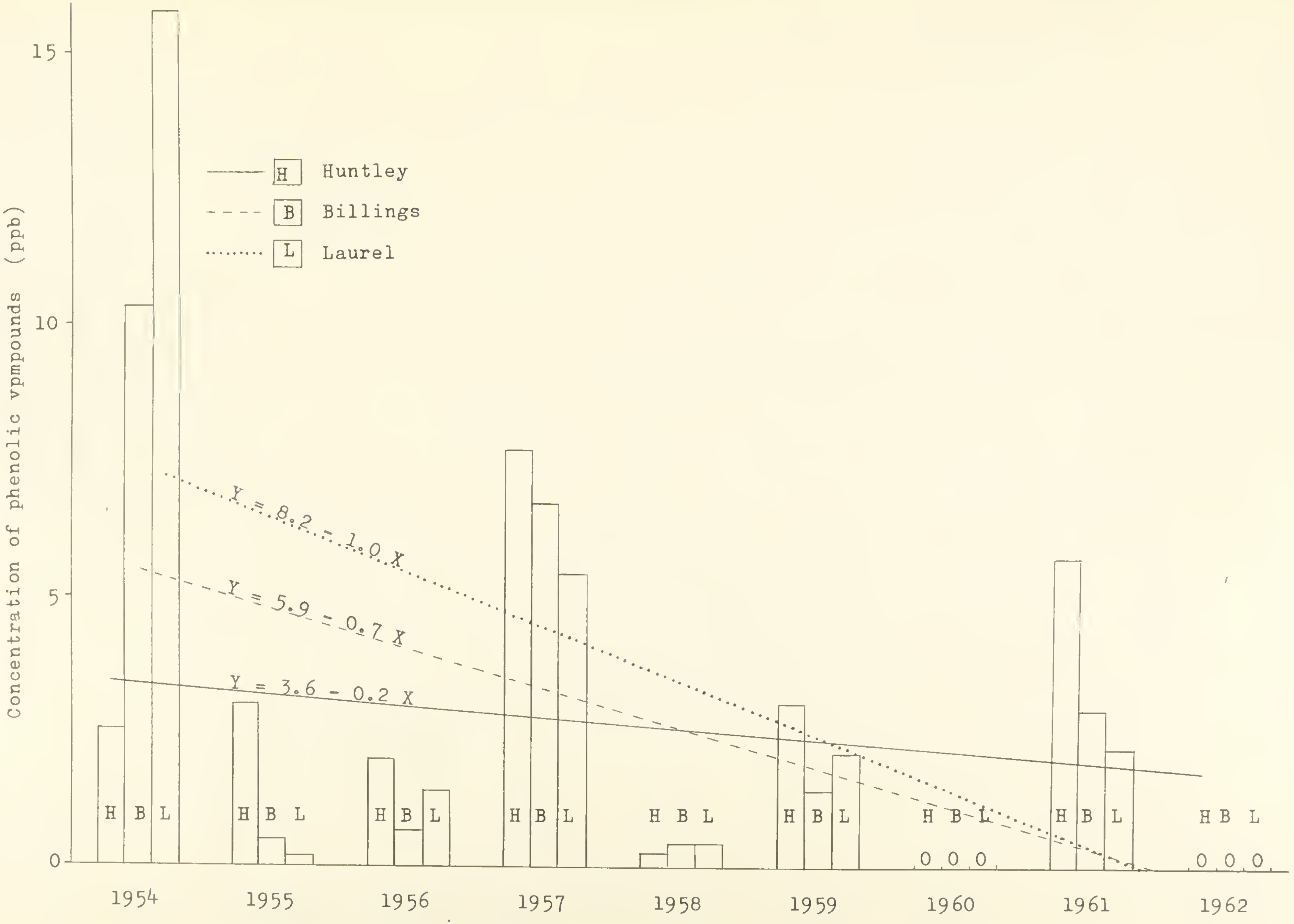


Figure 24. Concentration of phenolic compounds in Yellowstone River water samples prior to and since 1958 during the summer, 1954-62.

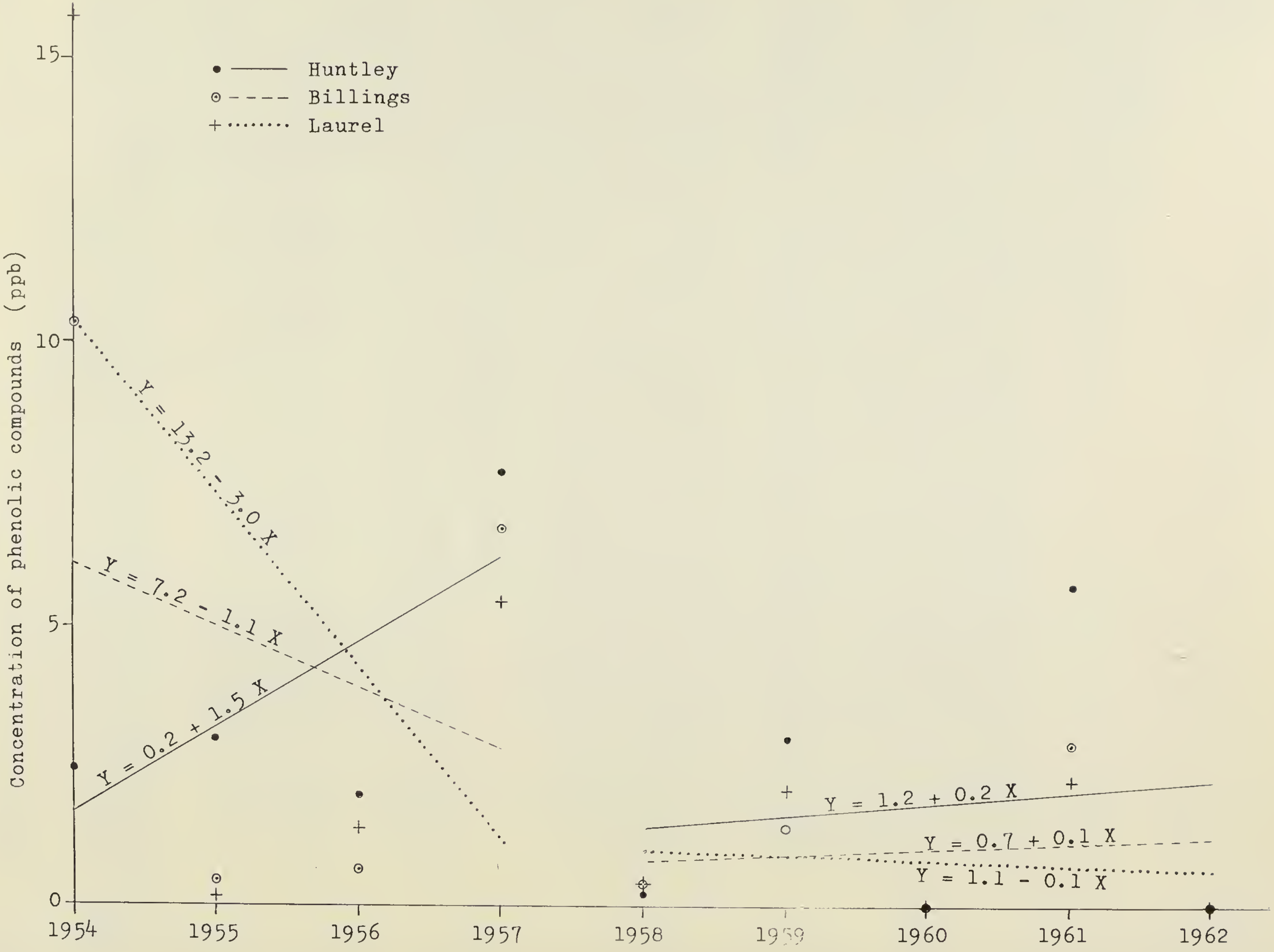


Figure 25. Concentration of phenolic compounds in Yellowstone River water samples during the fall, 1953-62.

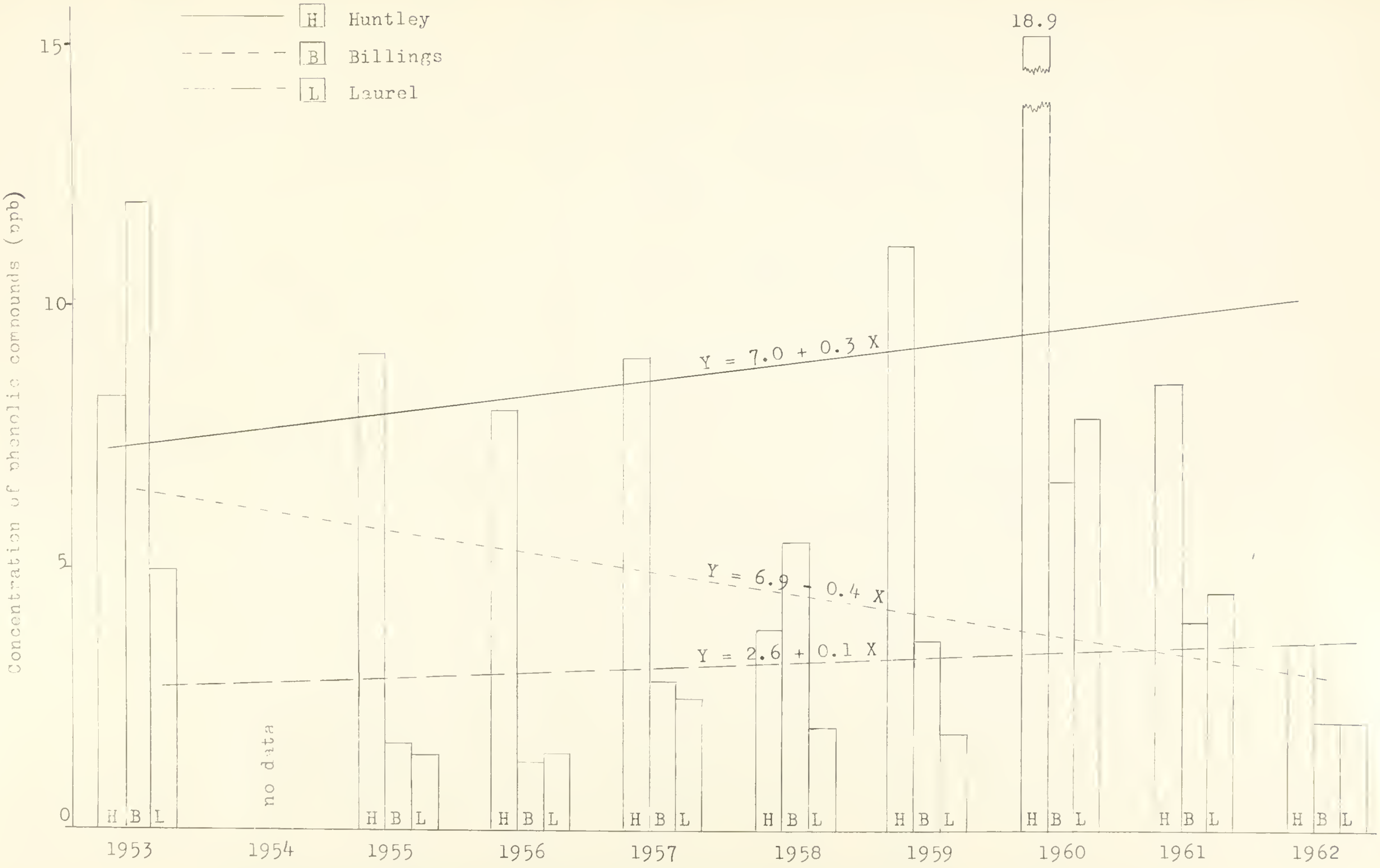
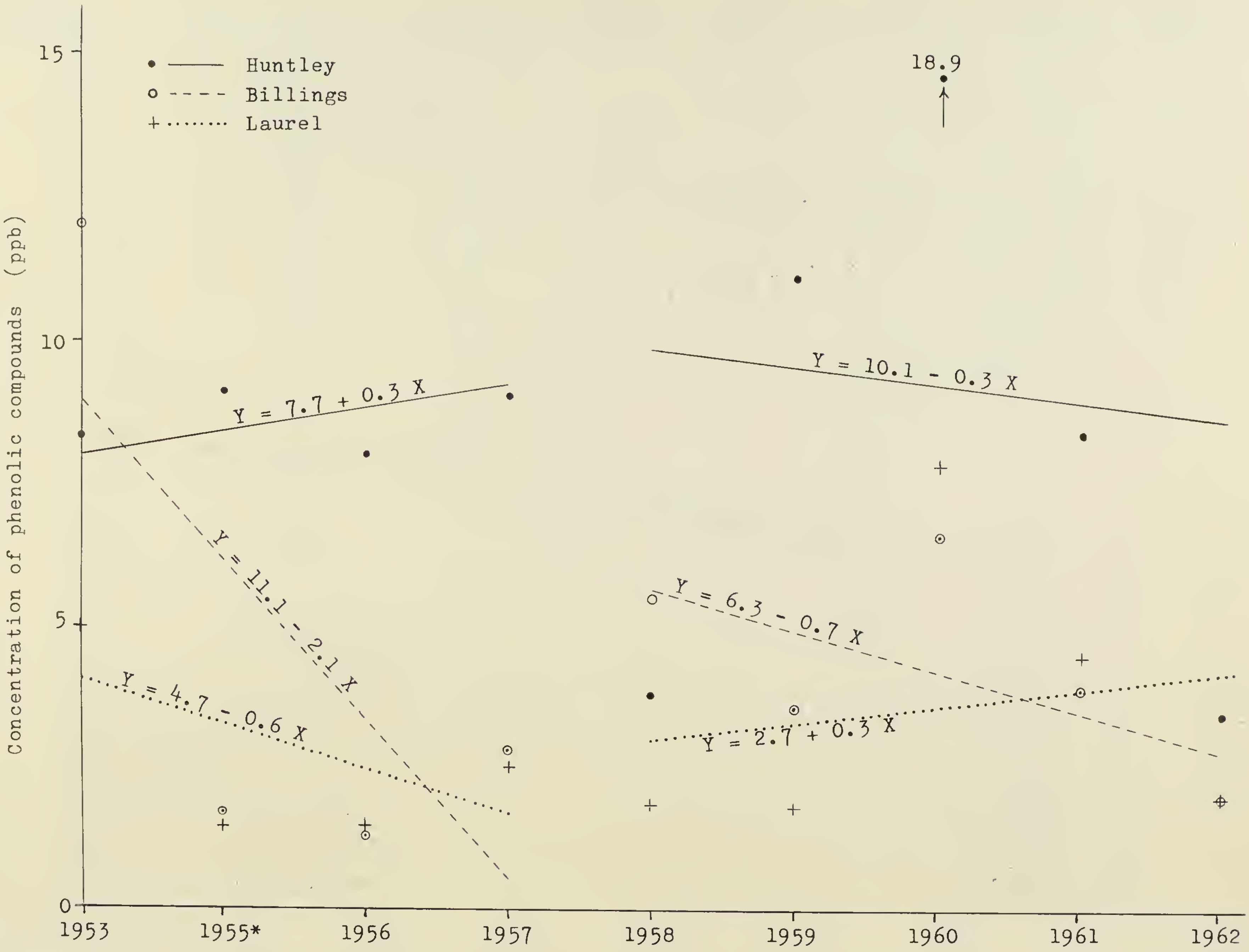


Figure 26. Concentration of phenolic compounds in Yellowstone River water samples prior to and since 1958 during the fall, 1953-62. (*no data obtained during the fall of 1954).



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Appendix A. Phenolic compounds in Yellowstone River water samples from the Billings area and river water temperature at Billings, 1953-62.

	Phenols (ppb)			Difference (ppb)			
Date	Above Laurel	Above Billings	Huntley	Billings-Laurel	Huntley-Billings	Huntley-Laurel	Temp. °F.
1953							
9-30	0	0	0	0	0	0	54
10-31	15.0	30.0	20.0	15.0	-10.0	5.0	48
12-7	10.0	5.0	5.0	-5.0	0	-5.0	34
1954							
2-1	20.0	150.0	90.0	130.0	-60.0	70.0	32
3-16	30.0	20.0	40.0	-10.0	20.0	10.0	38
3-31	15.0	20.0	30.0	5.0	10.0	15.0	36
5-5	0	0	0	0	0	0	46
6-23	30.0	20.6	7.6	-9.4	-20.6	-22.4	64
8-3	1.4	0	0	-1.4	0	-1.4	68
1955							
2-3	1.0	0	12.0	-1.0	12.0	11.0	33
3-1	8.0	1.0	23.0	-7.0	22.0	15.0	33
4-11	2.0	1.0	11.0	1.0	10.0	9.0	40
5-2	2.0	0	5.0	-2.0	5.0	3.0	56
6-1	2.5	1.5	4.0	1.0	2.5	1.5	57
7-1	0.5	1.5	14.0	1.0	12.5	13.5	59
8-1	0	0	0	0	0	0	72
9-6	0	0	1.0	0	1.0	1.0	67
10-1	0	0	0	0	0	0	50
10-31	0.5	1.0	7.0	0.5	6.0	6.5	--
12-5	4.0	4.0	20.2	0	16.2	16.2	33
1956							
2-7	0	0	16.0	0	16.0	16.0	33
3-6	4.4	4.4	25.0	0	20.6	20.6	33
4-3	0	0	12.0	0	12.0	12.0	41
4-30	2.0	1.5	5.0	-0.5	3.5	3.0	44
6-13	0	0	0	0	0	0	56
7-17	0	0	0	0	0	0	64
8-7	0	0	--	0	--	--	63
9-4	4.0	2.0	6.0	-2.0	4.0	2.0	55
10-2	0	0	0	0	0	0	52
10-31	0	1.0	7.0	1.0	6.0	7.0	38
12-6	4.0	3.0	17.0	-1.0	14.0	13.0	30
1957							
1-4	5.0	2.5	20.0	-2.5	17.5	15.0	32
2-6	8.0	7.0	16.0	-1.0	9.0	8.0	31
3-4	2.0	3.0	10.0	1.0	7.0	8.0	32
4-2	2.0	2.0	10.0	0	8.0	8.0	42
5-6	1.0	0	0	-1.0	0	-1.0	56
6-7	6.0	4.0	0	-2.0	-4.0	-6.0	51
7-2	3.0	5.0	8.0	2.0	3.0	5.0	--
8-5	0.2	0	0	-0.2	0	-0.2	68

Date	Phenols (ppb) Above Laurel	Phenols (ppb) Above Billings	Phenols (ppb) Huntley	Difference (ppb) Billings-Laurel	Difference (ppb) Huntley-Billings	Difference (ppb) Huntley-Laurel	Temp. °F.
1957							
9-3	13.0	15.0	15.0	2.0	0	2.0	60
9-30	5.0	5.0	8.5	0	3.5	3.5	58
11-6	2.5	0.5	3.5	-2.0	3.0	1.0	34
12-3	0	3.0	15.0	3.0	12.0	15.0	31
1958							
1-6	3.5	0.6	1.3	-2.9	0.7	-2.2	32
3-4	0	0	1.0	0	1.0	1.0	37
4-4	0	0	0	0	0	0	46
4-30	16.6	3.8	7.6	-12.8	3.8	-9.0	47
6-16	16.7	17.9	14.7	1.2	-3.2	-2.0	56
8-4	0.8	0.7	0.6	-0.1	-0.1	-0.2	72
9-2	0	0	0	0	0	0	63
9-30	0	0	0	0	0	0	51
11-3	5.3	12.1	3.5	6.8	-8.6	-1.8	40
12-1	0.4	4.3	8.0	3.9	3.7	7.6	33
12-31	0.5	1.2	14.0	0.7	12.8	13.5	31
1959							
2-3	0	0	6.8	0	6.8	6.8	31
3-8	4.7	8.5	14.7	3.8	6.2	10.0	34
4-6	0	0	0	0	0	0	50
5-4	0	0	0	0	0	0	52
6-1	0	0	0	0	0	0	56
6-30	1.1	1.6	3.2	0.5	1.6	2.1	54
8-3	2.1	2.7	2.7	0.6	0	0.6	70
9-1	3.1	0	3.1	-3.1	3.1	0	66
10-5	4.9	7.1	8.2	2.2	1.1	3.3	52
11-2	0	2.0	8.0	2.0	6.0	8.0	42
12-1	0.6	1.7	17.2	1.1	15.5	16.6	34
1960							
1-6	0	1.6	32.6	1.6	31.0	32.6	32
3-1	13.1	10.1	38.1	-2.0	28.0	25.0	32
4-7	0	0	11.4	0	11.4	11.4	54
5-2	0	1.2	2.0	1.2	0.8	2.0	52
5-30	2.5	2.5	2.5	0	0	0	62
6-27	0	0	0	0	0	0	64
8-30	0	0	0	0	0	0	62
11-1	0	1.0	0	1.0	-1.0	0	42
12-5	15.6	12.2	37.8	-3.4	25.6	22.2	34
1961							
1-9	12.6	13.8	19.8	1.2	6.0	7.2	36
1-9	7.2*	11.4*	--	4.2	--	--	36
2-13	1.0	1.0	8.3	0	7.3	7.3	39
4-11	1.0	1.1	3.2	0.1	2.1	2.2	48
5-16	3.8	4.5	10.8	0.7	6.3	7.0	55
6-6	3.6	2.4	4.8	-1.2	2.4	1.2	56

Date	Phenols (ppb)			Difference (ppb)			Temp. °F.
	Above Laurel	Above Billings	Huntley	Billings-Laurel	Huntley-Billings	Huntley-Laurel	
1961							
7-24	5.3	5.8	6.9	0.5	1.1	1.6	72
8-15	1.2	0	5.3	-1.2	5.3	4.1	70
9-18	0	2.8	4.9	2.8	2.1	4.9	63
10-16	4.4	2.4	4.9	-2.0	2.5	0.5	55
11-7	0	0	2.0	0	2.0	2.0	36
12-5	9.2	9.2	18.4	0	9.2	9.2	36
1962							
1-15	12.0	7.5	20.5	-4.5	13.0	8.5	32
2-12	19.8	22.5	55.9	2.7	33.4	36.1	31
4-3	5.6	18.1	9.8	12.5	-8.3	4.2	43
5-8	6.9	18.8	13.8	11.9	-5.0	6.9	52
8-13	0	0	0	0	0	0	65
9-17	0	0	0	0	0	0	58
11-1	0	0	0	0	0	0	--
12-6	4.0	4.0	7.0	0	3.0	3.0	--

* - collected by Laurel and Billings water treatment plant personnel, respectively.

Appendix B. Results of chemical analysis of Yellowstone River water samples from the Billings area, 1961-62.

Sampling period	Water temp. °F.	Dissolved oxygen		pH (Sorenson scale)	Alkalinity (ppm as $CaCO_3$)		Hardness as $CaCO_3$ (ppm)	Turbidity units	Chloride (ppm Cl)	Sulphate (ppm SO_4)	Nitrate (ppm NO_3)	Phosphate (ppm PO_4)		Filtrable residue at 103°C (ppm)	Loss on ignition at 600°C (ppm
		Actual (ppm)	Corrected for altitude (% sat.)		CO_3	Total						Ortho-	Total		
Above Laurel															
Aug 21-31 1961	72	10.0	110	9.0	8	131	160	20		45					40
Sept 12 1961	51	12.4	110	8.4	12	122	170	41		45	0.2		0.2		60
Nov 7-9 1961				7.8	0	122	140			33	0.3	0.8	0.8		65
Dec 4-7 1961	34	14.2	113	8.3	0	128	170	7		42	0.4	0.1	0.2	155	25
Mar 26-29 1962	48	12.0	115	8.2	6	110	164	30	11	41	0.2		0.1	165	40
Oct 29-30 1962									8	36	0		0		
Clark's Fork River															
Dec 4-7 1961														430	10
Mar 26-29 1962	50	12.4	123	8.4	4	182	310	400	15	222	1.6		0.1	500	70
Above Billings															
Aug 21-31 1961	76	10.8	128	9.2	16	136	180	31		93					90
Sept 12 1961	50	12.4	108	8.1	0	134	190	410		76	0.5		0.4		70
Nov 7-9 1961				8.5	0	153	210			91	0.4	0.7	0.8		55
Dec 4-7 1961	33	13.0	100		0	153	210	8		122	0.4	0	0	270	30
Mar 26-29 1962	46	12.2	115	8.4	12	132	193	45	12	101	0.4		0.2	280	60
Oct 29-30 1962									8	80	0.4		0.1		
O'Leary's Gravel Pit															
Aug 21-31 1961	74	5.5	70	8.0											
Nov 7-9 1961				8.3.	0	153	240			117	0.3	1.7	2.0		90
Dec 4-7 1961	34	9.6	75	8.1	0	153	240	25		130	0.5	0.2	0.4	240	75
Mar 26-29 1962	49	11.8	115	8.4	6	132	193	55	12	111	0.5		0.7	280	60
Oct 29-30 1962									11	123	0.3		0.6		
Farm House															
Nov 1961				8.5	0	146	240			93	0.4	0.7	0.8		95
Dec 4-7 1961	33	11.1	86	8.1	0	159	220	14		125	0.2	0	0.1	270	80
Mar 26-29 1962	41	11.4	99	8.4	6	132	200	75	12	99	0.4		0.8	290	70
Huntley															
Aug 21-31 1961	74	5.5	70	8.6	14	150	230	29		113					90
Sept 12 1961	50	10.0	88	8.4	0	221	240	360		152	0.4		0.4		120
Nov 7-9 1961				8.4	0	159	260			152	0.3	1.0	1.4		90
Dec 4-7 1961	33	12.0	93	8.0	0	171	250	29		175	0.4	0	0.1	330	80
Mar 26-29 1962	49	10.4	100	8.4	8	140	218	35	11	154	0.5		0.2	360	25
Oct 29-30 1962									9	90	0.2		0		
Pompey's Pillar															
Aug 21-31 1961	74	8.4	97	9.0	2	158	240			171					63
Sept 12 1961	50	9.6	83	8.2	0	183	320	550		113	2.2		0.2		130
Nov 7-9 1961	36				0	317	220			113	0.3	1.0	1.6		90
Dec 4-7 1961	33			8.2	0	153	220	29		145	0.2	0	0.2	260	60
Mar 26-29 1962	41	12.0	98	8.1	0	196	185	160	8	109	0.5		0.2	280	70
Dec 6 1962									10	108	0.2		0		

Appendix C. MPN coliform organisims of Yellowstone River water samples, 1960-63.

Date	MPN per 100 ml.				
1960	Laurel	Billings	Forsyth	Miles City	Glendive
1-18	75	150			
1-25			210	75	150
2-1		150			
2-8			93	430	930
2-15		93			
2-22	15		93	93	230
2-29		150			
3-7			43	43	230
3-14		930			
3-21			2300		930
3-28	430	2300		210	
4-4					230
4-5			150		
4-11		230		15	
4-18	9.1				430
4-19			43		
4-25		230		9.1	
5-2			93		
5-3					230
5-16		210		430	
5-23			93		21
5-24	3.6				
5-31		43		75	
6-6			2300		430
6-13		930		2300	
6-20	2300		9300		9300
6-27		230		430	
7-5			2300		
7-6					2300
7-12		430		150	
7-19			93		430
7-25	93			93	
7-26		430			
8-1			43		9300
8-15	230	210		93	
8-22			930		930
8-29		93		230	
9-6					93
9-12		23		43	
9-19	23		430		93
9-26		430		9300	
10-3			23000		23000
10-10		4300		430	
10-17			43000		9300

Date	MPN per 100 ml.				
1960	Laurel	Billings	Forsyth	Miles City	Glendive
10-24	23	430			
10-31			2300	430	
11-14		2300	2300	150	
11-28		1500		150	
12-5		150	210		43
12-12				3.6	
12-19			43		150
12-26	43				
12-27				23	
1961					
1-9				23	750
1-10			230		
1-16	23	930			
1-23			230	43	
1-24					93
1-30		930			
2-6	23	930		210	
2-13			43		4300
2-20	43	210		23	
2-27			230		230
3-6	3.6	930		230	
3-13			43		430
3-20	23	230		23	
4-3	9.1	930	93	23	430
4-17			430		150
4-24	23	2300		23	
5-1			930		43
5-8	23	93		43	
5-15			4300		93
5-22	430	4300		4300	
5-29			23000		4300
6-5	9300	930		9300	
6-12			9300		9300
6-19	930	430		93	
7-24	150	75		430	
7-31			150		23000
8-7	150	430		430	
8-14			150		2300
8-21	75	430		93	
9-4	430		230		
9-5		9300		150	930
9-18			4300		15000
9-25	230	9300		23000	
10-2			43000		15000
10-9	75	930		43000	
10-16			93000		
10-17					93000
10-23	150	930		4300	
11-6	150	2300		43000	
11-13			43000		7500

Date	MPN per 100 ml.				
1961	Laurel	Billings	Forsyth	Miles City	Glendive
12-4	23	43	4300	23000	4300
12-26	75			930	
1962					
1-2		2300	2300		4300
1-8	430	930		430	
1-15			430		930
1-22	150	4300		430	
1-29					2300
2-5	230	2300	930	4300	
2-12			930		430
2-18	1500				
2-19		930		9300	
2-26			93		93
3-5	150	2300		75	
3-12			930		23
3-19	43	2300		430	
4-30			9300		9300
5-7	4300	2100		1500	
5-14			23000		9300
5-21	4300	1500		2300	
5-28			9300		1500
6-4	4300	2300		4300	
6-11					9300
6-12			2300		
6-18	2300	750		23000	
7-16			43000		43000
7-23	230	230		2300	
7-30					750
7-31			2300		
8-6	2300	2300		2300	
8-13					4300
8-20	2300	430	9300	4300	
9-17					430
9-24	150	930		43	
9-25			1500		
10-8	43	4300		2300	
10-15			23000		
10-16					15000
10-22	23	4300		2300	
10-29					230
11-5	23	2300			
11-13					930
11-14			43000		
12-3	93	1500		2300	2300
12-5			24000		
12-17					1500

Date	MPN per 100 ml.				
1962	Laurel	Billings	Forsyth	Miles City	Glendive
12-26				2300	
12-27	43				
12-31		9300			43
1963					
1-28					2300
2-4	150	2300		2300	
2-11					2100
2-12			1500		
2-18	150	430		230	
2-26					430
3-4	93	430	750	4300	
3-11					930
3-18	9.1	430		150	
3-20			93		
4-15					150
4-22	23	4300		93	
5-1			23000		
5-6	430	430		2300	
5-14			23000		4300
5-20	430	2300		2300	
5-27					930
6-3				9300	
6-4	2300				
6-10		2300			21000
6-11			9300		
6-17	2300	9300		4300	
7-1	230	2300		2300	4300
7-15					930
7-16			2300		
7-22	9300	7500		2300	
7-29					230
8-5	150	430	430	150	
8-19	43	230		43	
9-2	93				
9-3		4300		4300	
9-5			7500		
9-10					430
9-19			2300		
9-23	230	7500		43000	
9-30					43000
10-3			93000		
10-7	43	2300		930	
10-14					930
10-21	23	430		150	
10-28					230
10-31			2300		

Date	MPN per 100 ml.				
1963	Laurel	Billings	Forsyth	Miles City	Glendive
11-4	93	2300		9300	
11-13					230
11-14			2300		
11-18	43	930		2300	
12-2		2300		23000	7.3
12-4	230				
Avg.	773	2070	9513	4158	5562
N	71	84	71	83	77